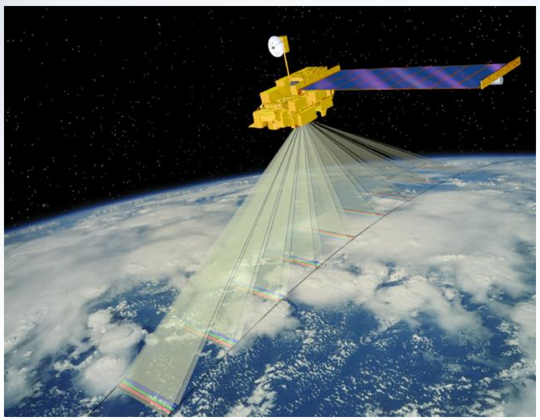
From Multi-angle Imaging SpectroRadiometer (MISR) to Multiangle SpectroPolarimetric Imager (MSPI)

: toward the PM2.5 monitoring and prediction of the future

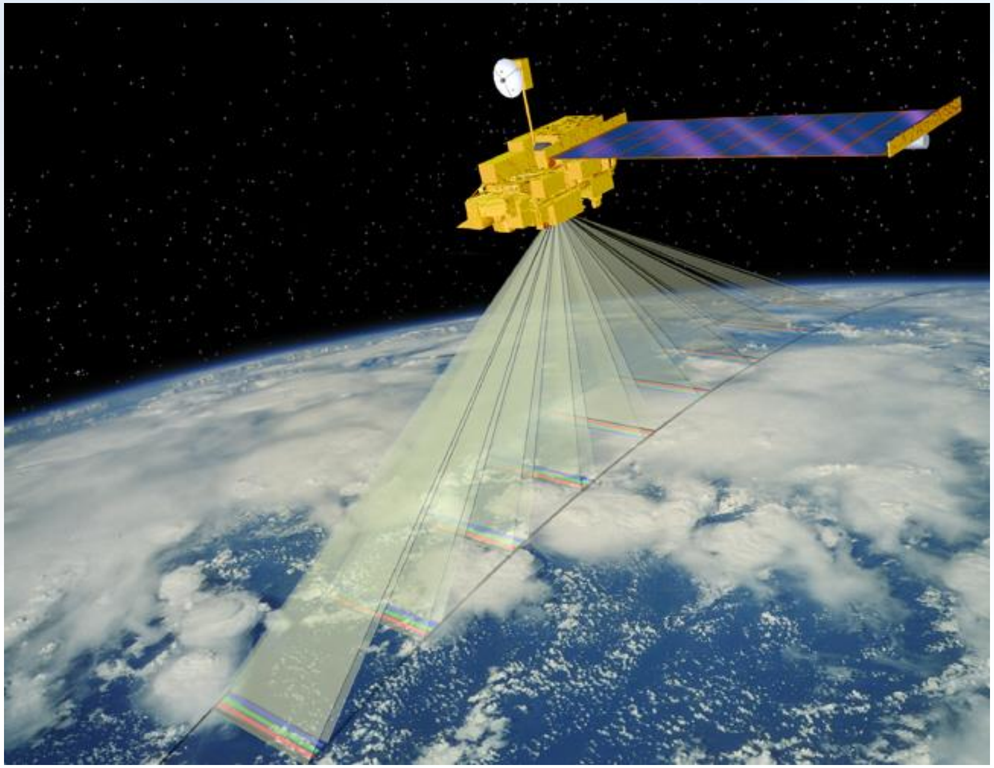


Huikyo Lee, Olga Kalashnikova, and Michael Garay

Jet Propulsion Laboratory (JPL), California Institute of Technology

Multi-angle Imaging SpectroRadiometer (MISR) on Terra

[March 2000 – present]



Nine view angles at Earth surface:
70.5º forward to 70.5º backward

Nine 14-bit pushbroom cameras

275 m - 1.1 km sampling

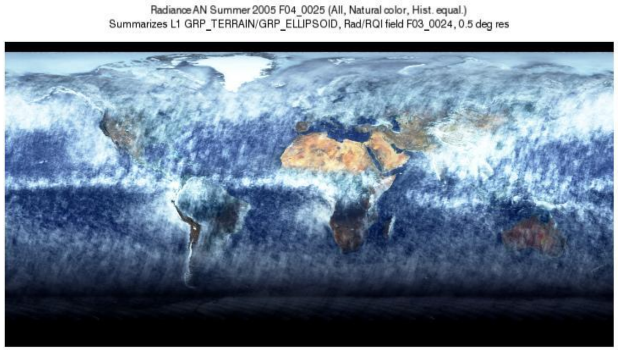
Four spectral bands at each angle:
446, 558, 672, 866 nm

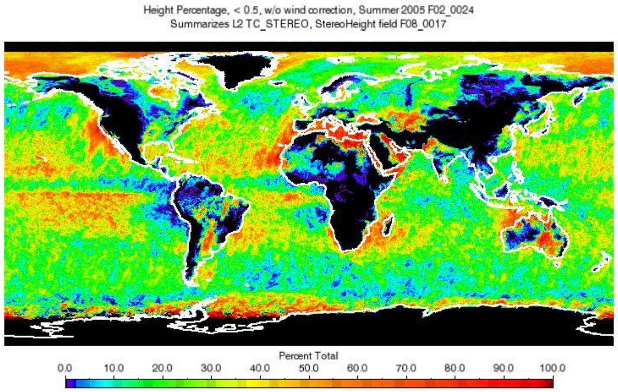
400-km swath: 9-day coverage
at equator, 2-day at poles

7 minutes to observe each scene
at all nine angles

Example MISR Standard Products

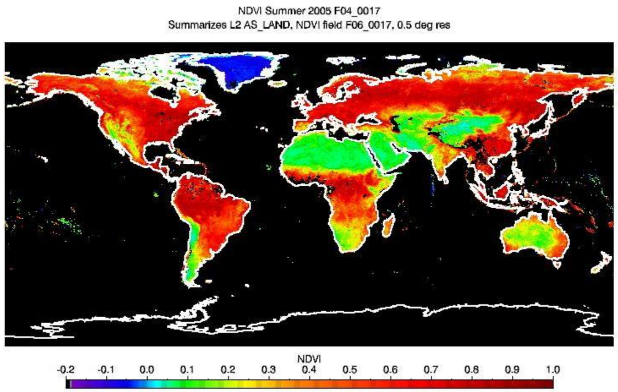
Radiance

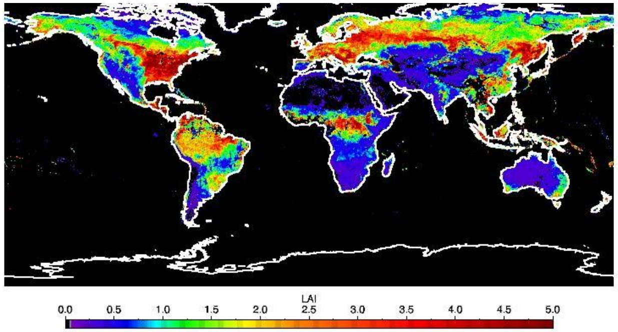




Cloud Top Height

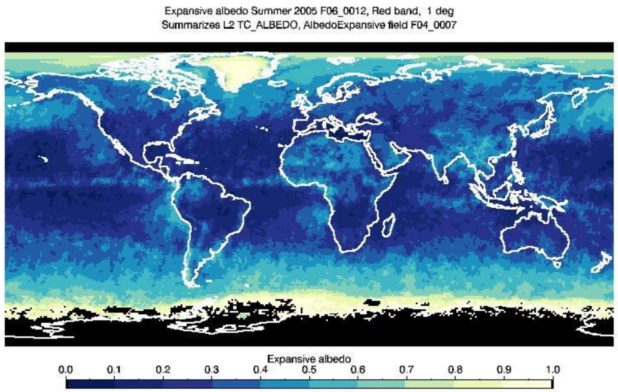
NDVI (normalized difference vegetation index)

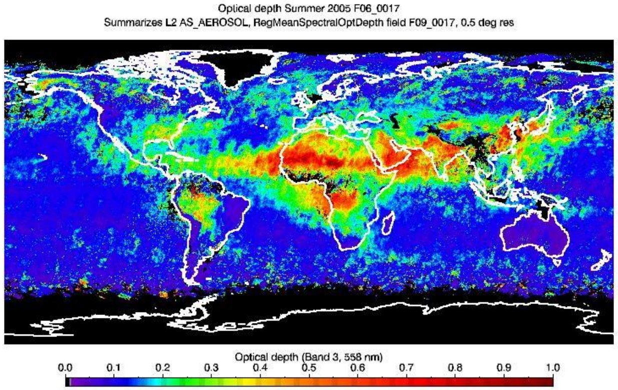




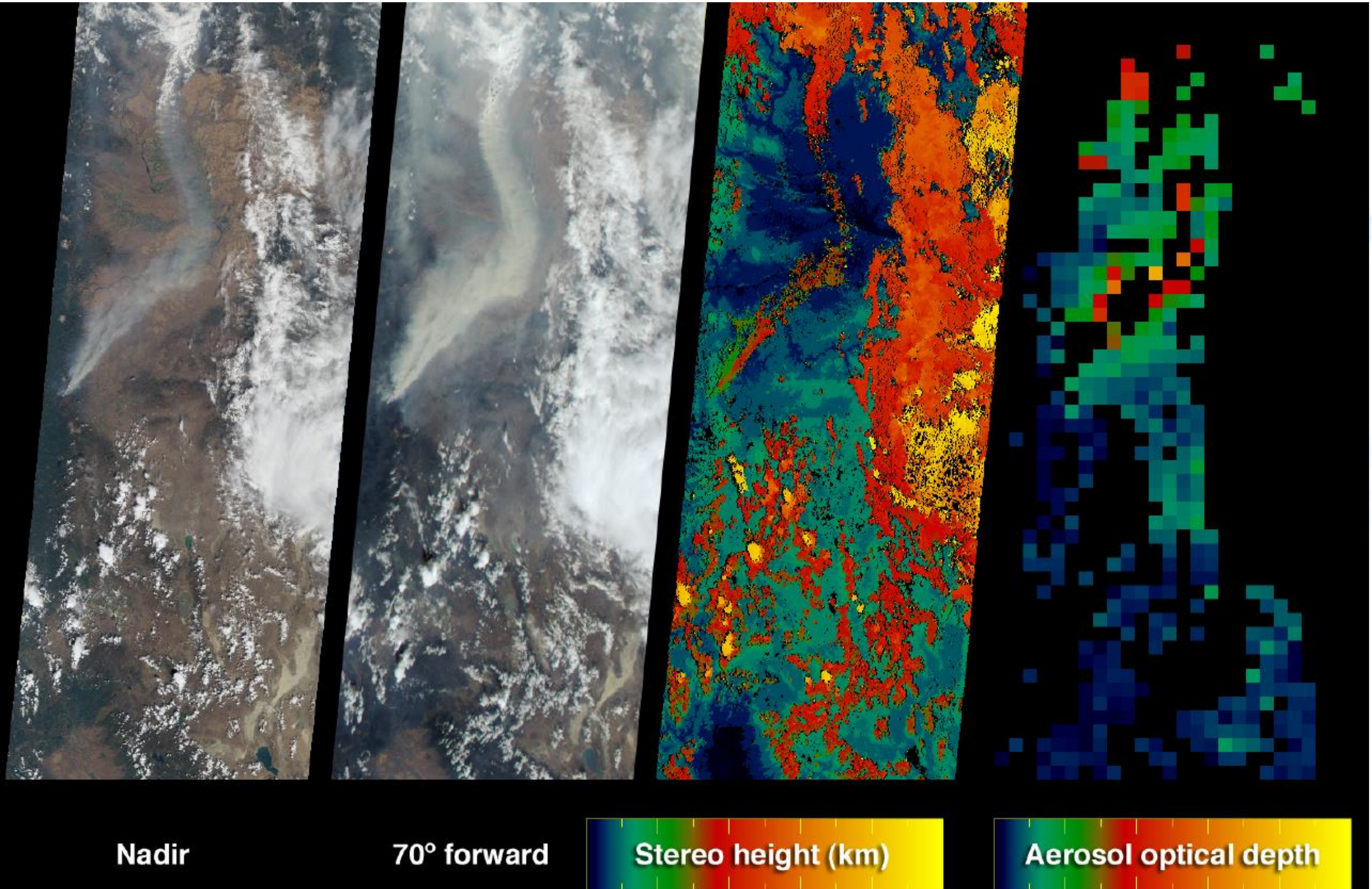
LAI (leaf area index)

Albedo



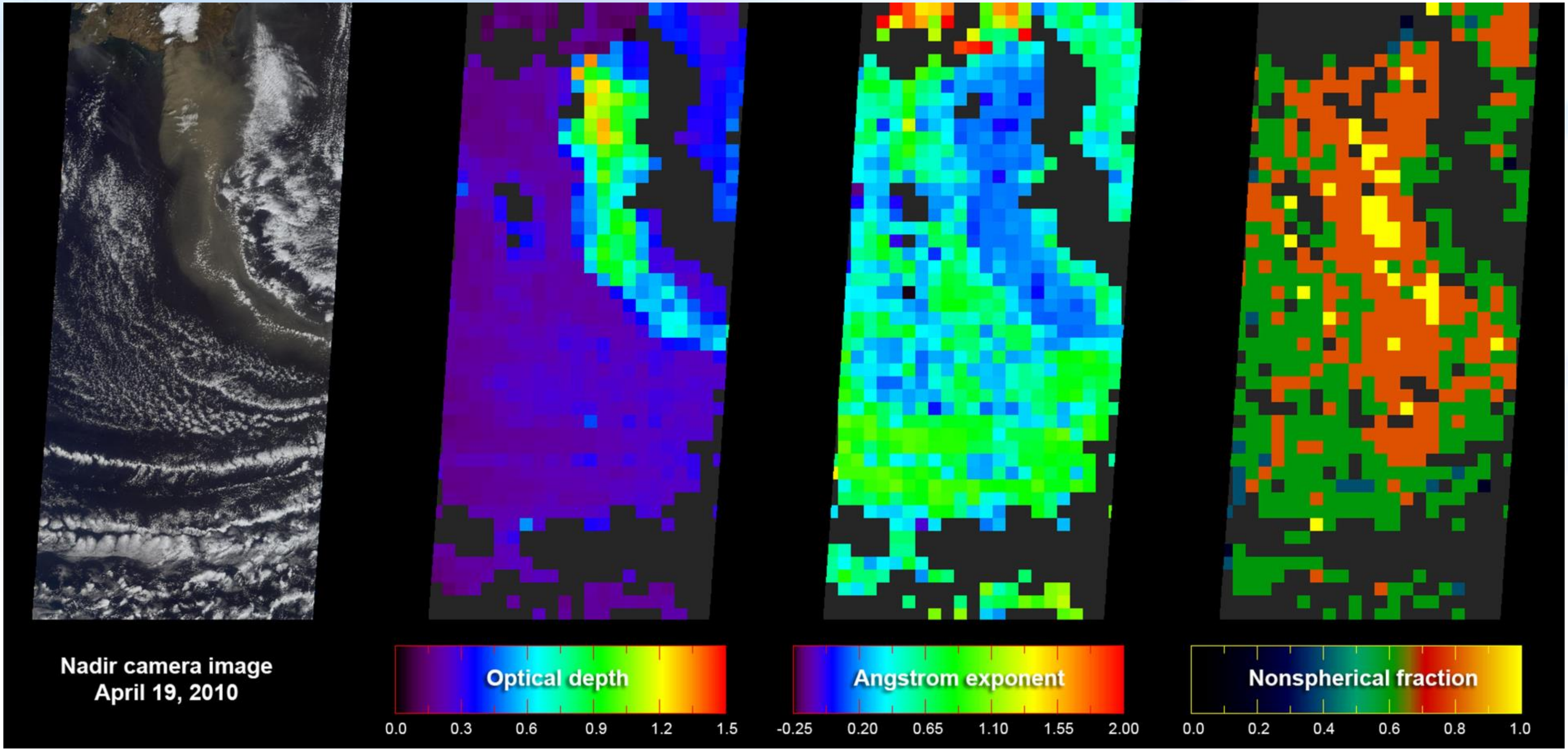


AOD (aerosol optical depth)



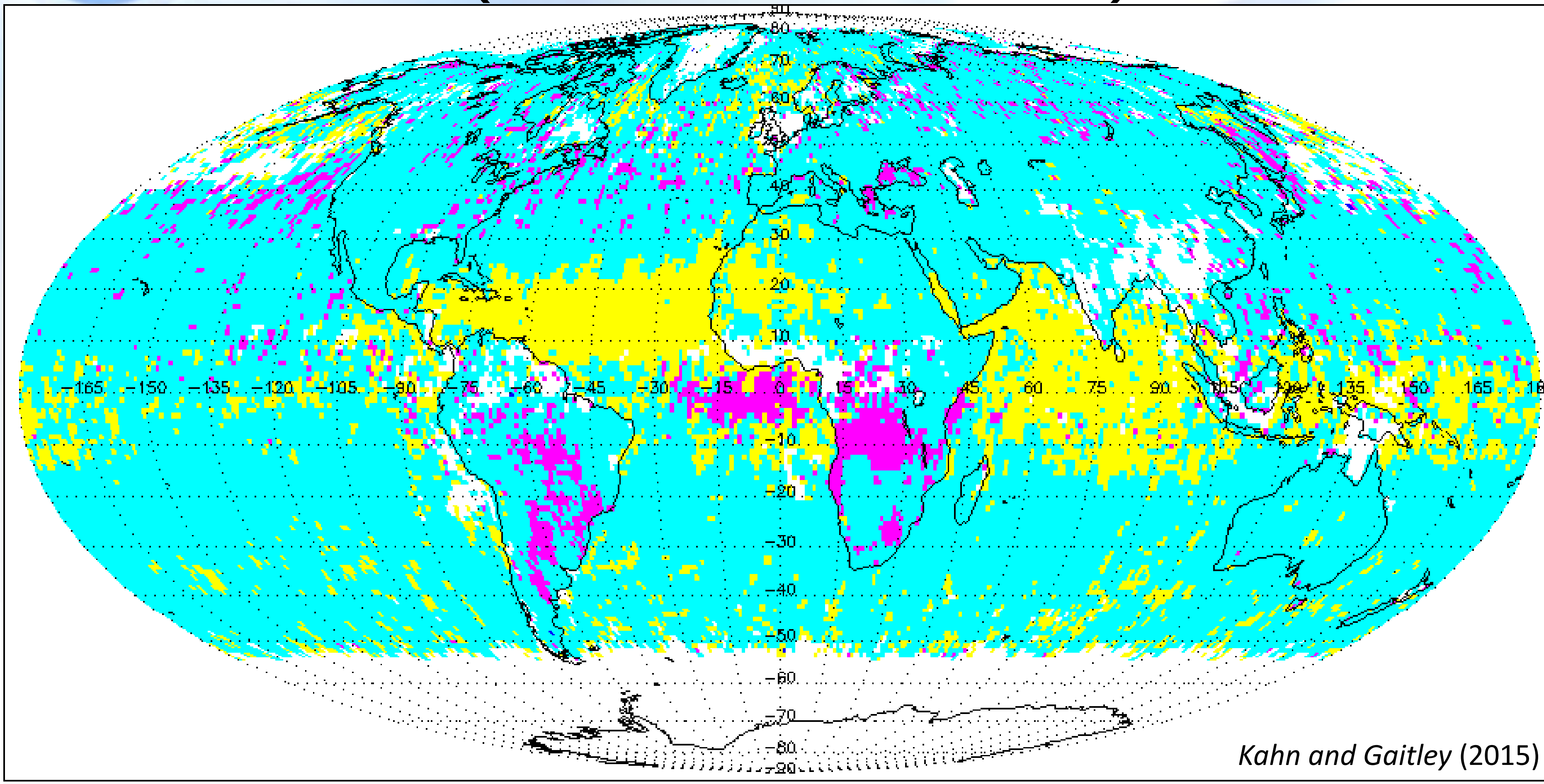
B&B Fire Complex - Oregon

Aerosol particle properties from MISR



MISR views of Eyjafjallajökull – 4/19/2010

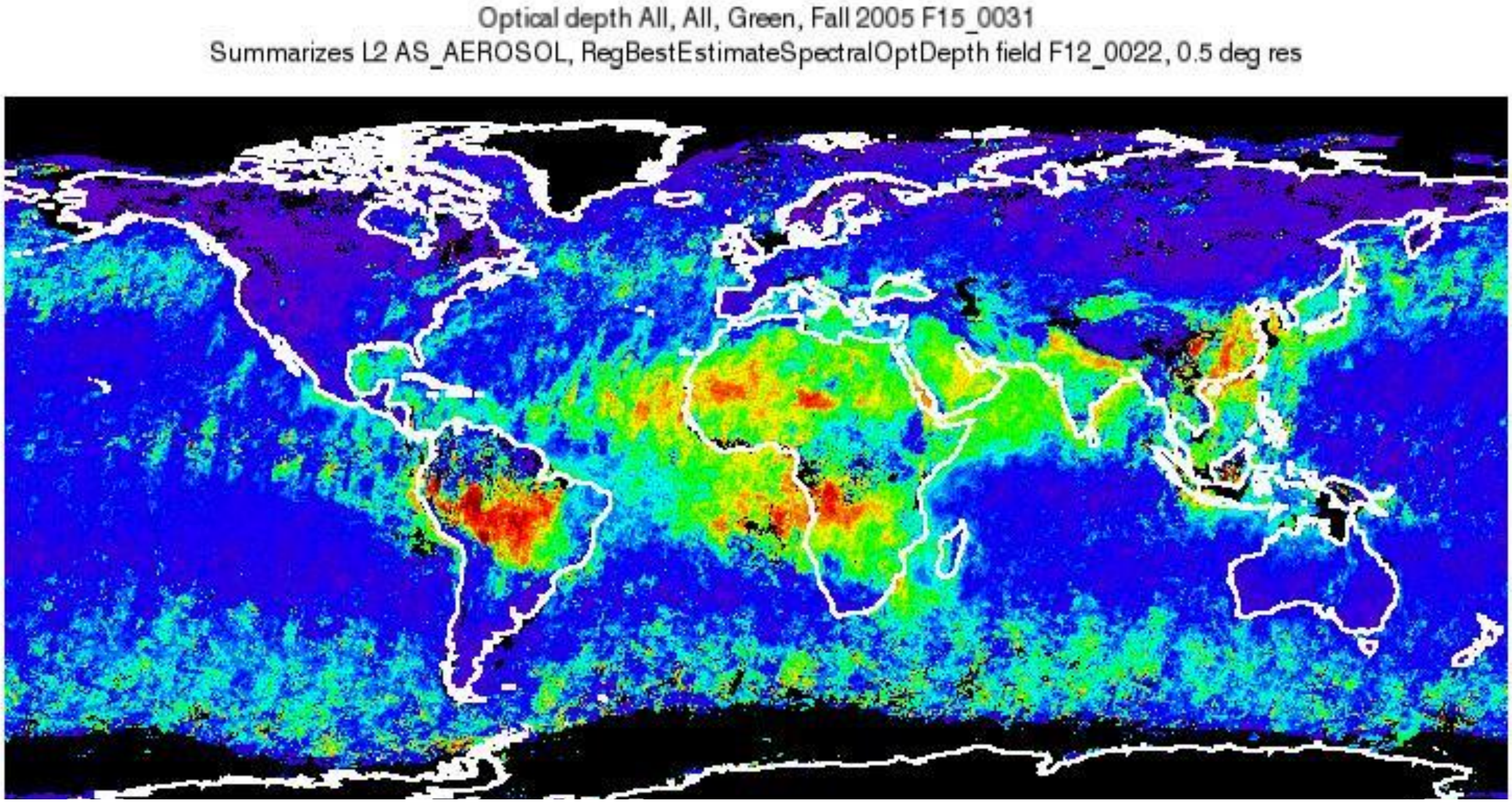
74 Aerosol Mixtures (Standard Product)



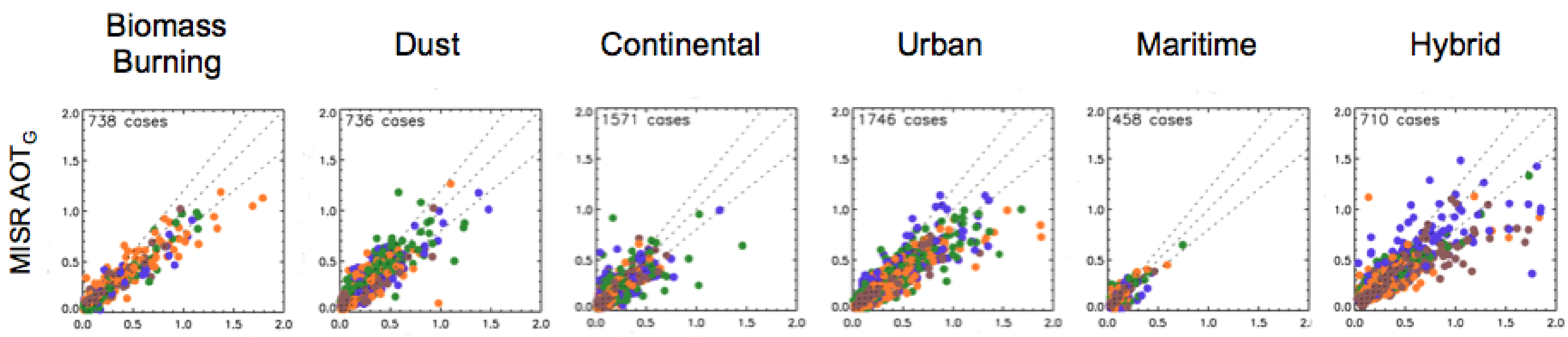
Kahn and Gaitley (2015)

Key

- Spherical Non-Absorbing
- Spherical Absorbing
- Non-Spherical
- Spherical Absorbing + Non-Spherical (Tie)
- Spherical Non-Absorbing + Non-Spherical (Tie)
- Spherical Absorbing + Spherical Non-Absorbing (Tie)



Optical depth All, All, Green, Fall 2005 F15_0031
Summarizes L2 AS_AEROSOL, RegBestEstimateSpectralOptDepth field F12_0022, 0.5 deg res



Biomass Burning
Dust
Continental
Urban
Maritime
Hybrid
MISR AOT$_G$
738 cases
736 cases
1571 cases
1746 cases
458 cases
710 cases
0.0
0.5
1.0
1.5
2.0

MISR V22 and V23 AOD

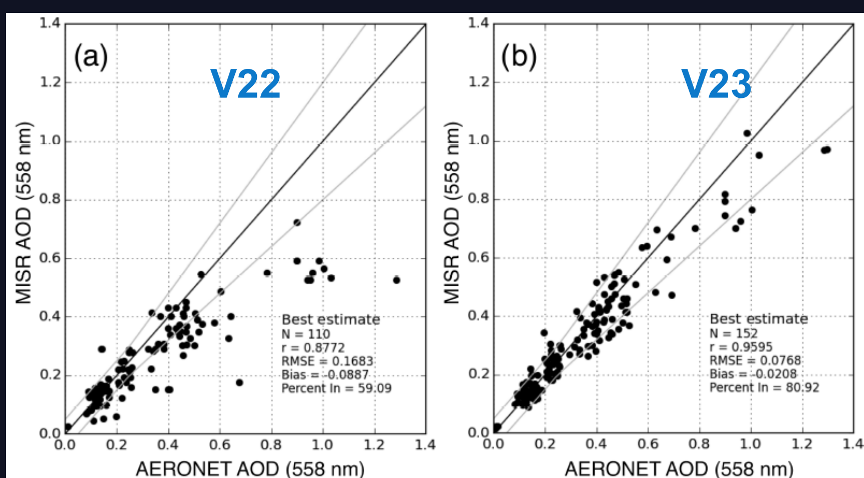
- *Version 22*
  - Martonchik et al (Springer, 2009): land
  - Kalashnikova et al (AMT, 2013): ocean

  - **17.4 km** products
  - variable: “RegBestEstimateSpectralOptDepth”
  > interpolated to 550 nm

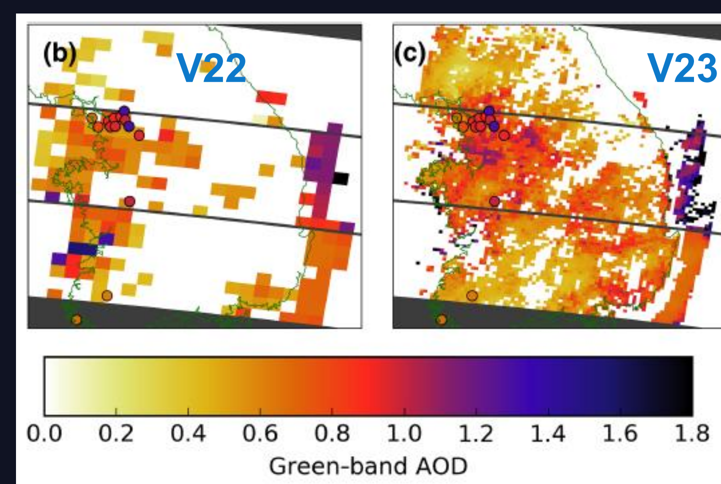
- *Recent Version 23*
  - Garay et al. (AMT, 2017): overall changes
  - Witek et al. (AMT, 2018): new inversion with uncertainty estimation (ensemble approach)

  - **4.4 km** products
  - variable: “Aerosol_Optical_Depth”

Validation of AOD during 2011-2013 DRAGON campaign



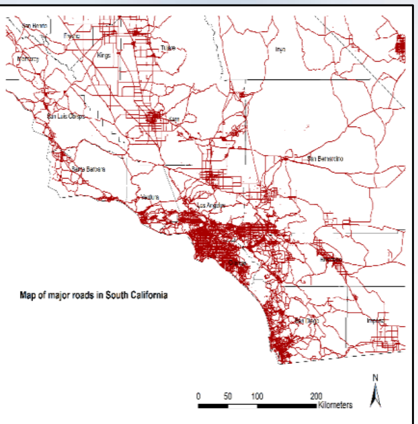
Retrieved MISR AOD over Korean peninsula (9 May 2012)

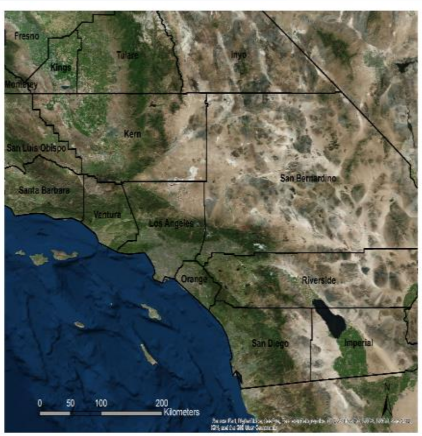


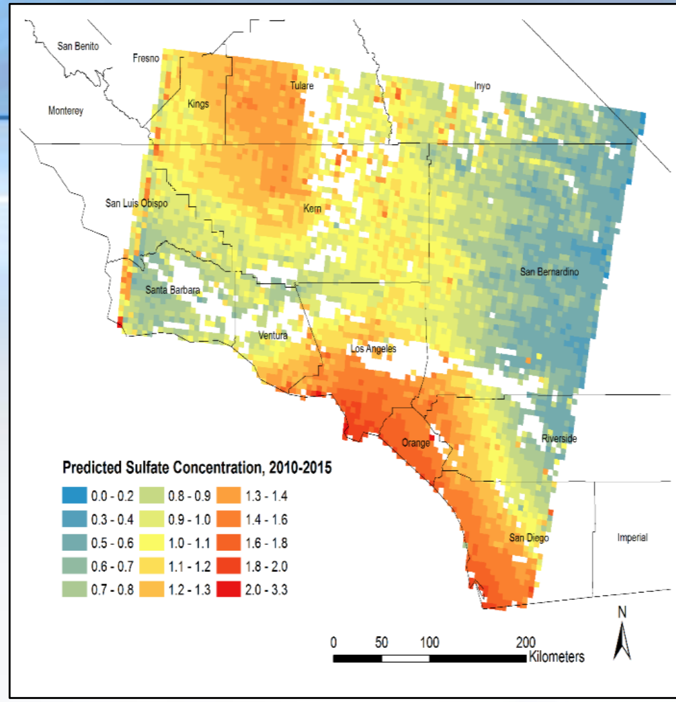
courtesy of Dr. Myungje Choi at Yonsei University

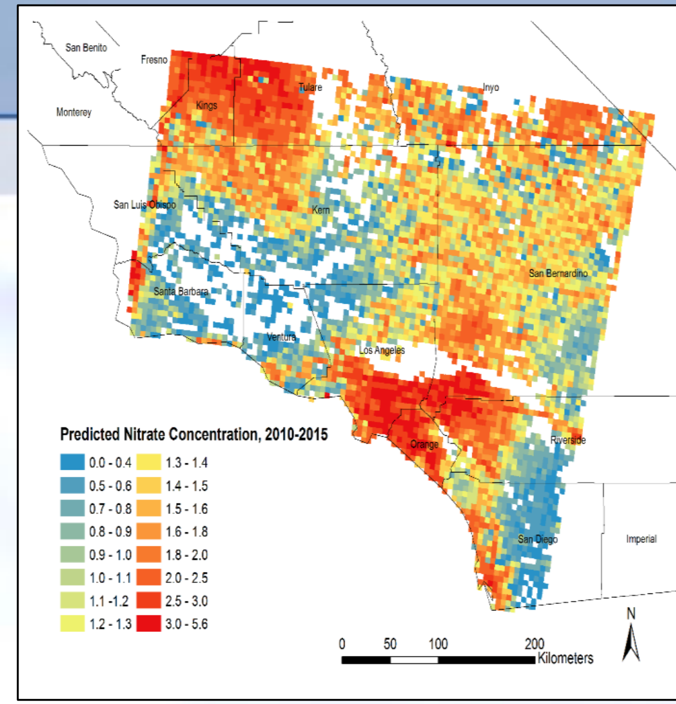
Prediction maps of long-term mean speciation concentrations, 2010-2015 (ug/m^3)

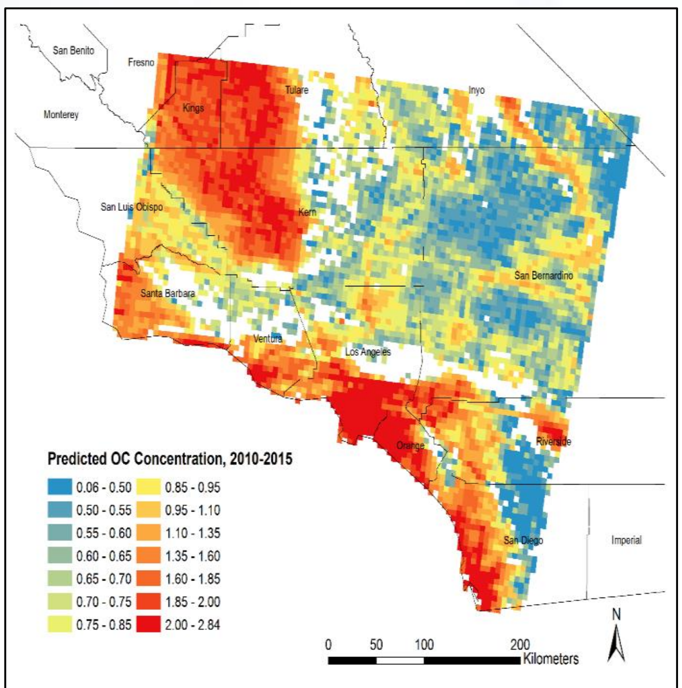
Preliminary results courtesy of Xia Meng and Yang Liu, Emory University

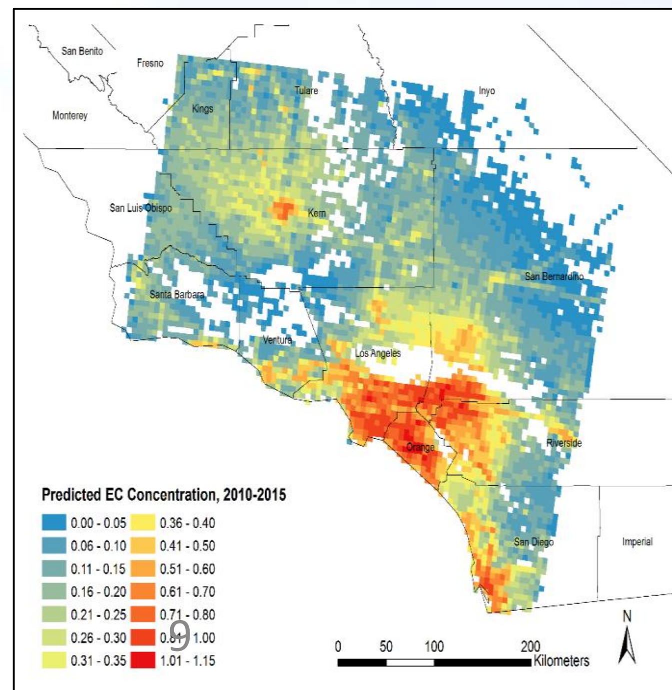




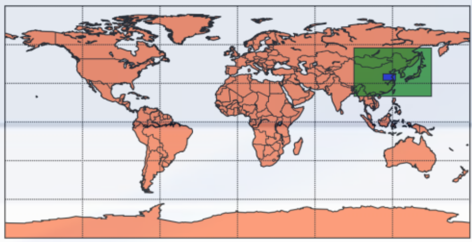


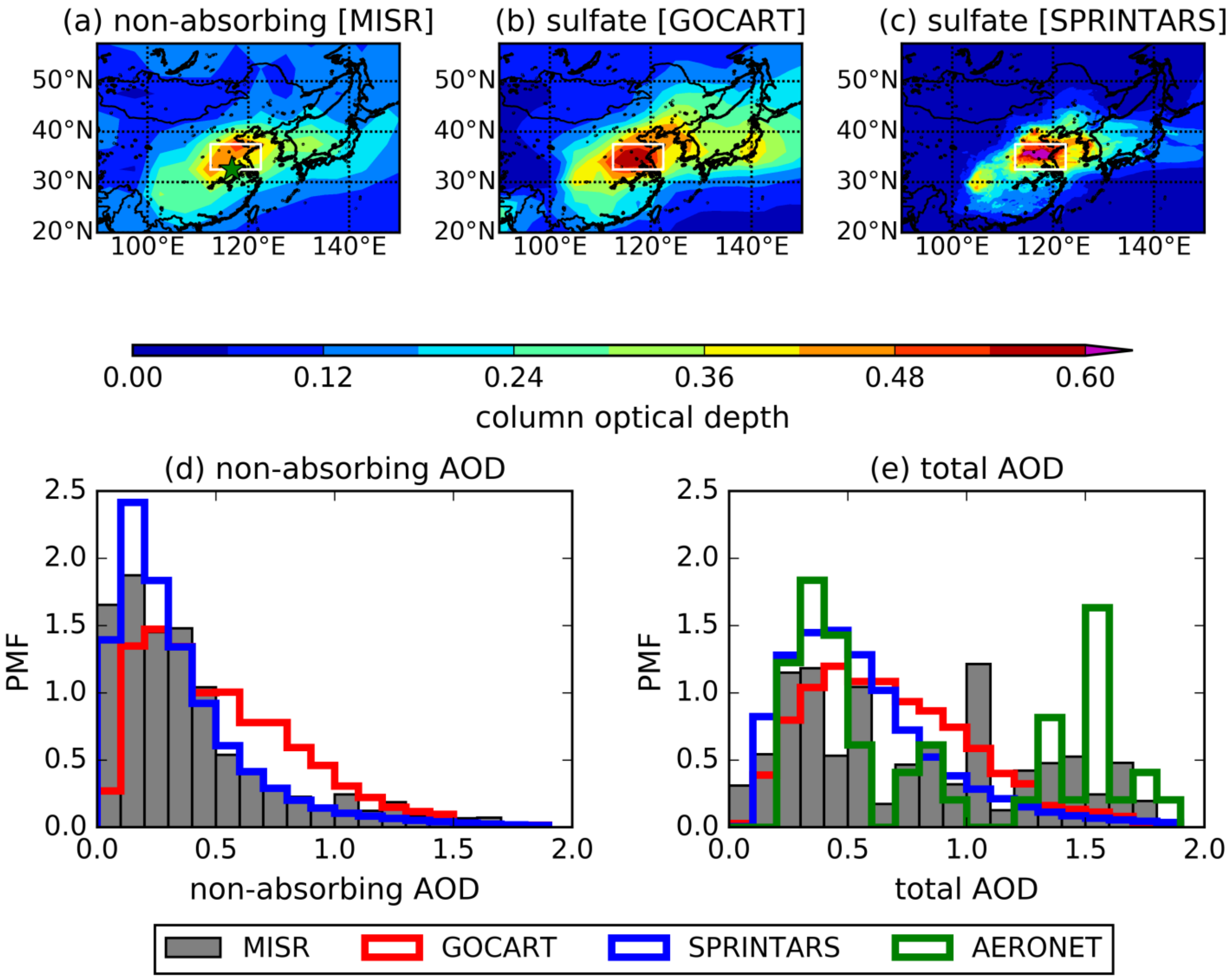






East Asia [July] (*Lee et al.*, 2016)

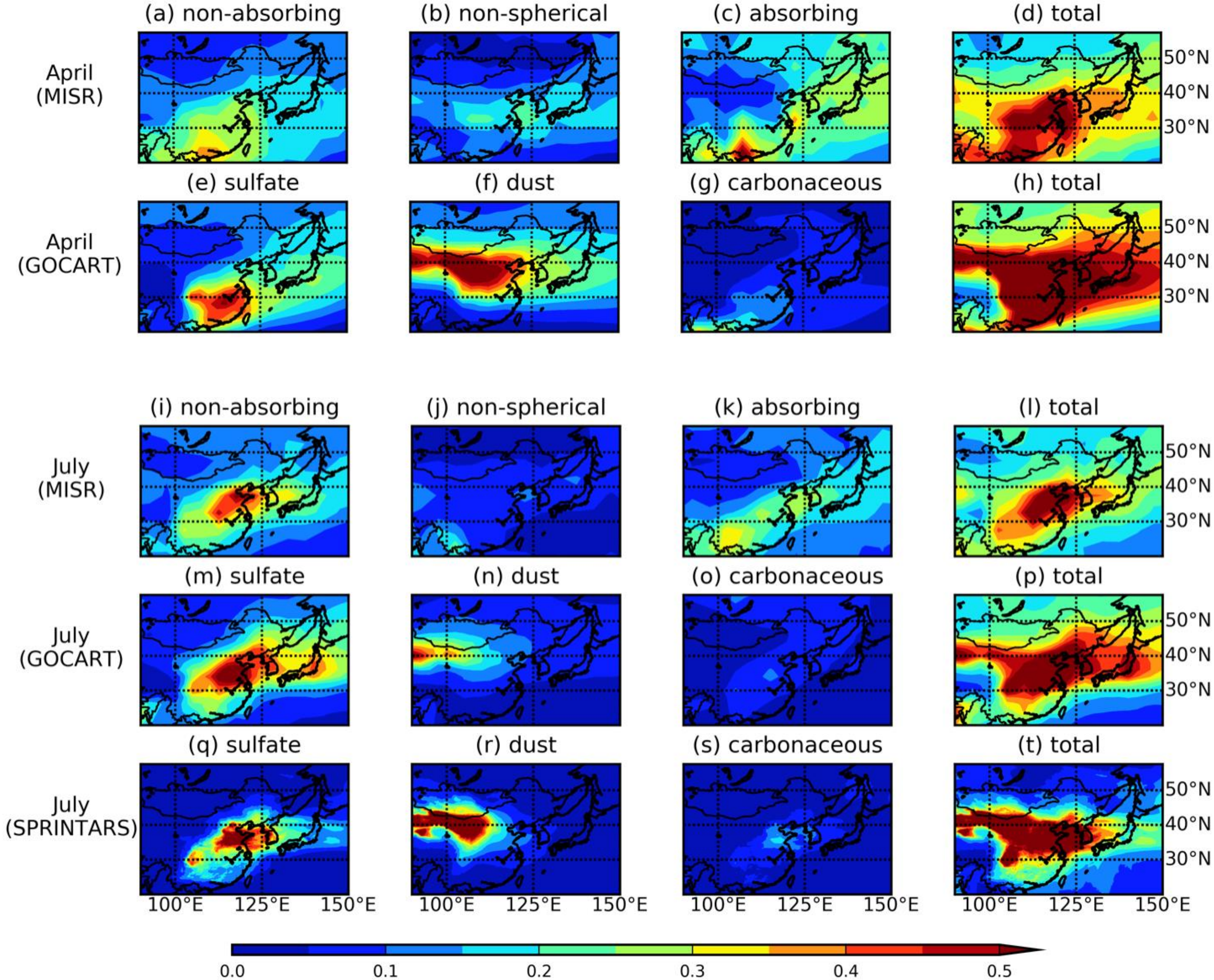




Aerosol Robotic Network (AERONET)

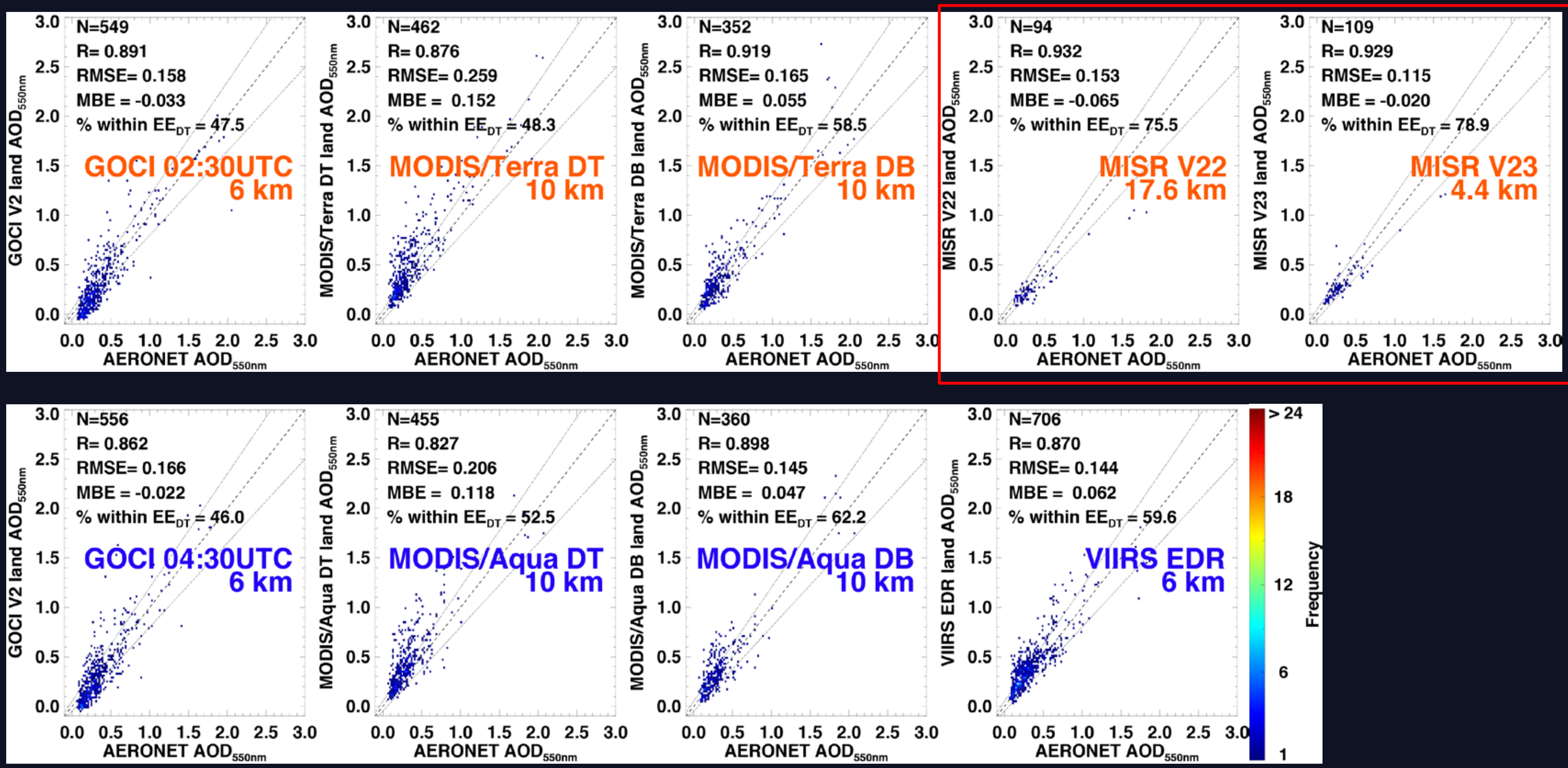
- Dominant type: nonabsorbing (sulfate)
- The observed distributions of total AOD do not follow the log normal distribution.

East Asia [April vs. July]



- The dominant sources of aerosols are different.
- MISR's non-spherical AOD in April

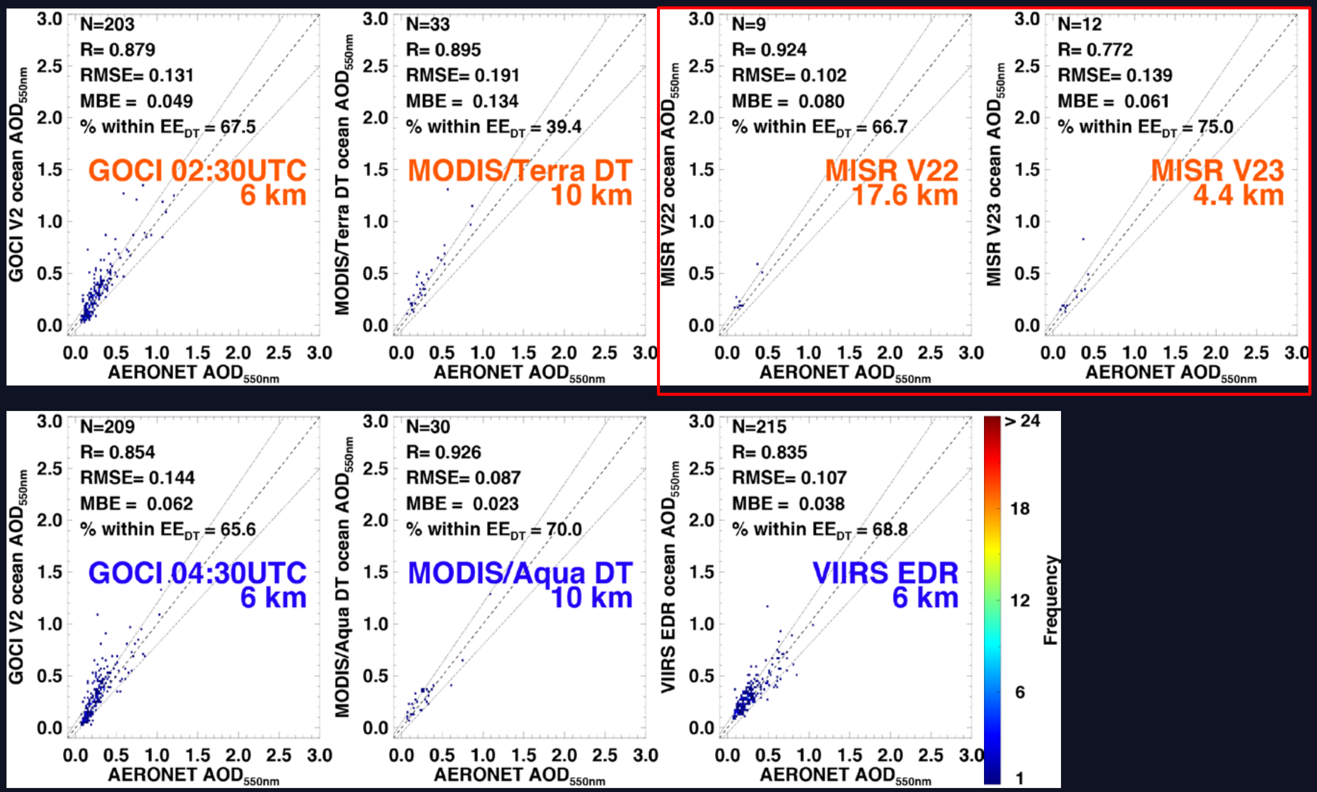
Satellite land AOD validation



- Collocation criteria:
  (spatially) average satellite pixels **within 25 km** radius from AERONET sites
  (temporally) average AERONET data **within 30 min** from satellite measurement
- $EE_{DT} = \pm (0.05 + 0.15 \times \text{AERONET AOD})$

courtesy of Dr. Myungje Choi at Yonsei University

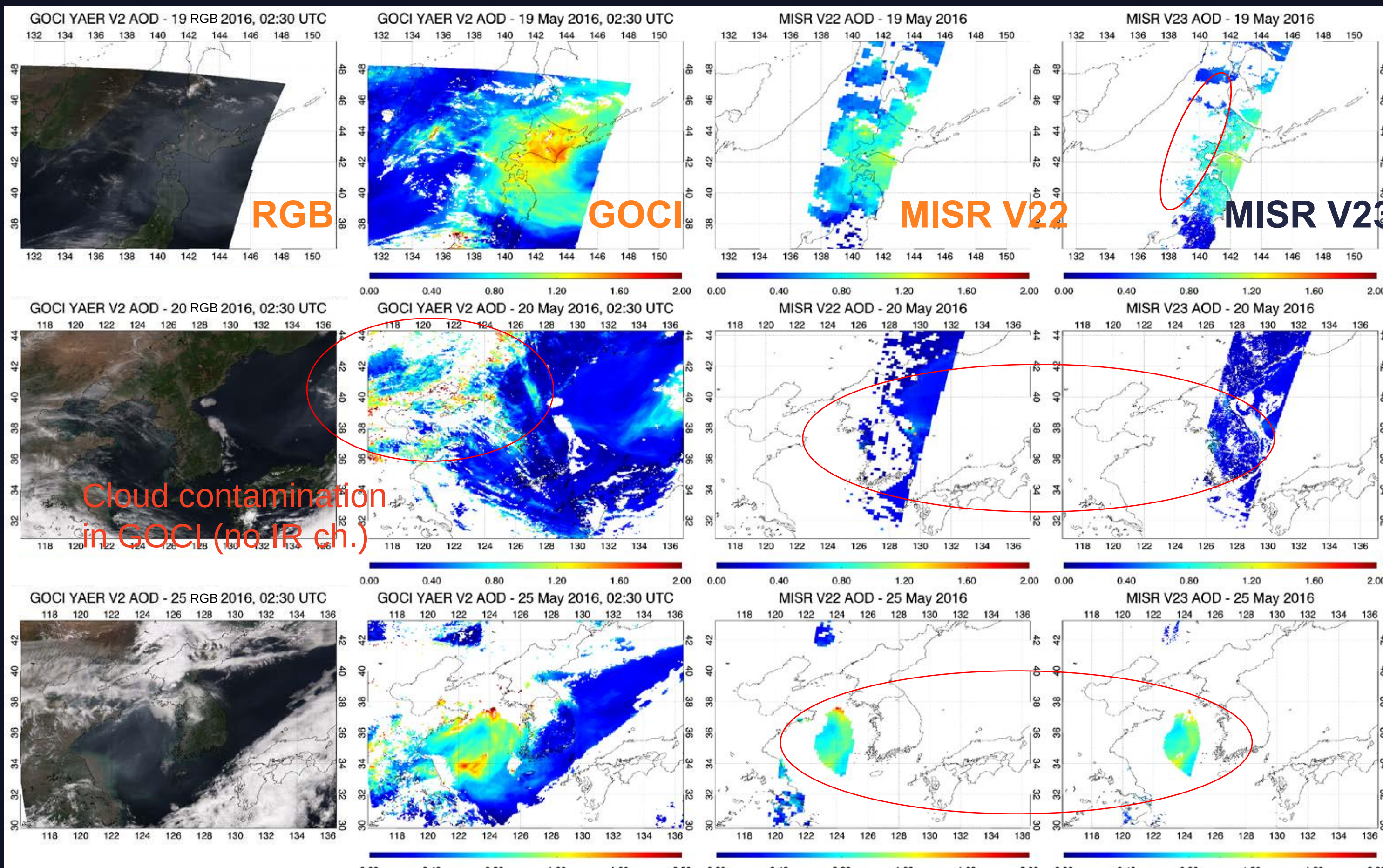
Satellite ocean AOD validation



- Collocation criteria:
  (spatially) average satellite pixels **within 25 km** radius from AERONET sites
  (temporally) average AERONET data **within 30 min** from satellite measurement
- $EE_{DT} = \pm (0.05 + 0.15 \times \text{AERONET AOD})$

courtesy of Dr. Myungje Choi at Yonsei University

GOCI, MISR V22, and MISR V23 AOD during 2016 KORUS-AQ campaign



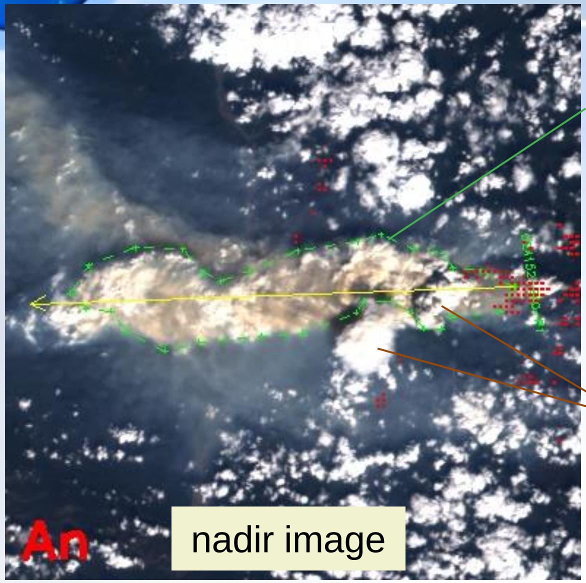
High AOD pixels retrieved in V22 are masked out in V23 (boundary b/w land and ocean)

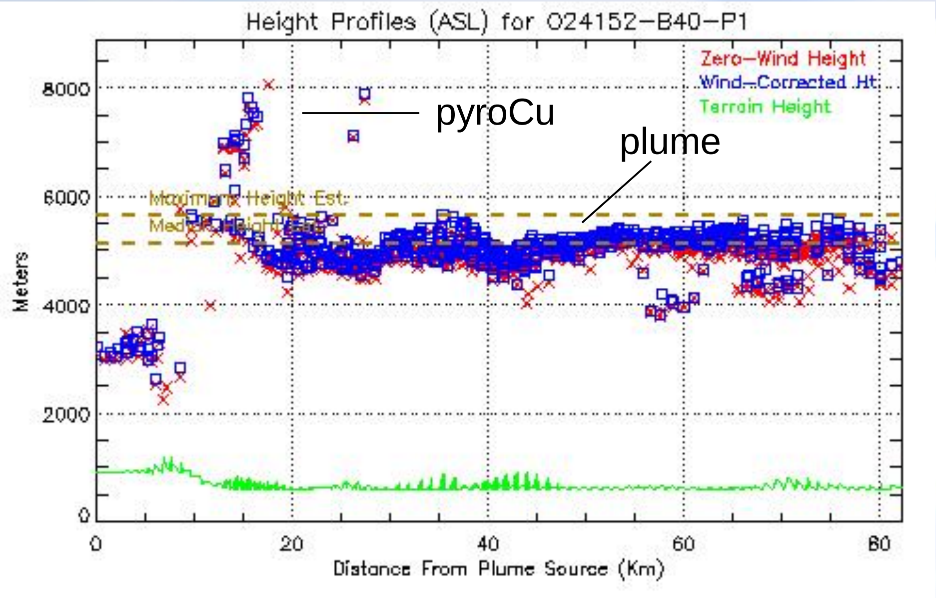
Low AOD pixels retrieved well in V23 (land)

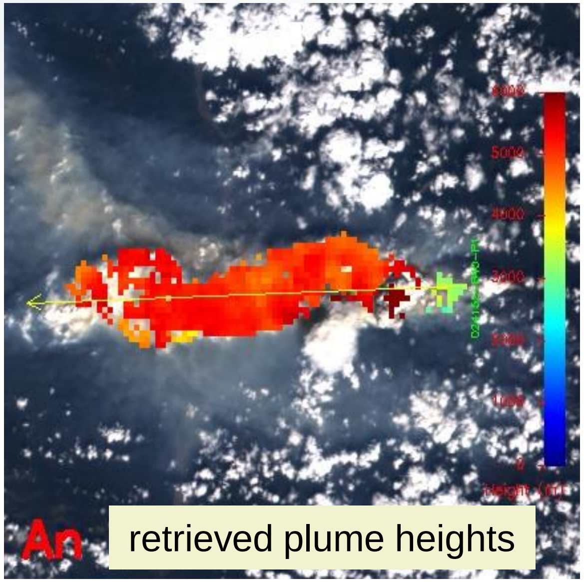
High AOD pixels retrieved well in V23 (ocean)

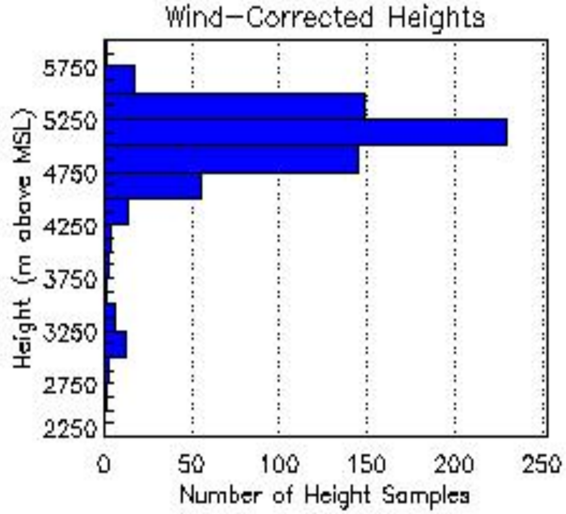
courtesy of Dr. Myungje Choi at Yonsei University

Example plume injection height retrieval, 2 July 2004







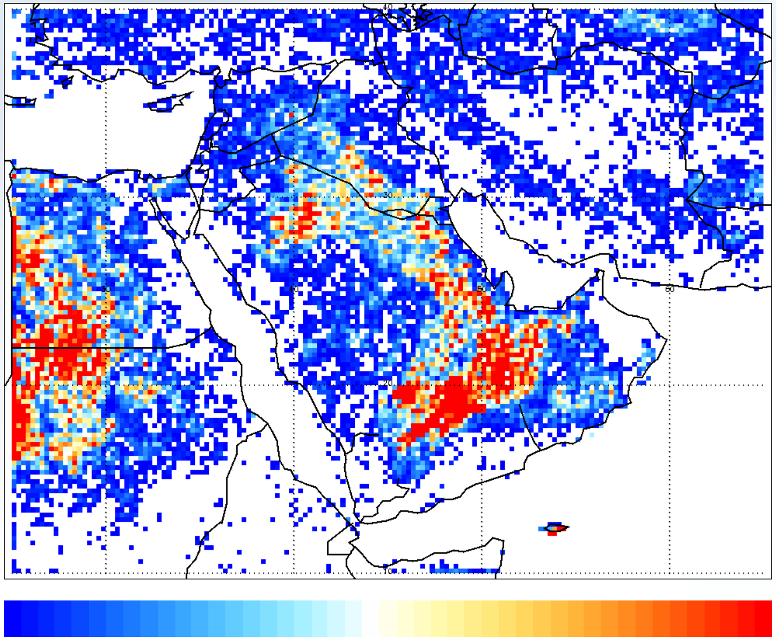


Smoke plume heights, and correction for motion effect on stereo parallax, are derived from MISR multiangle imagery.

Credit: D. Nelson (JPL)

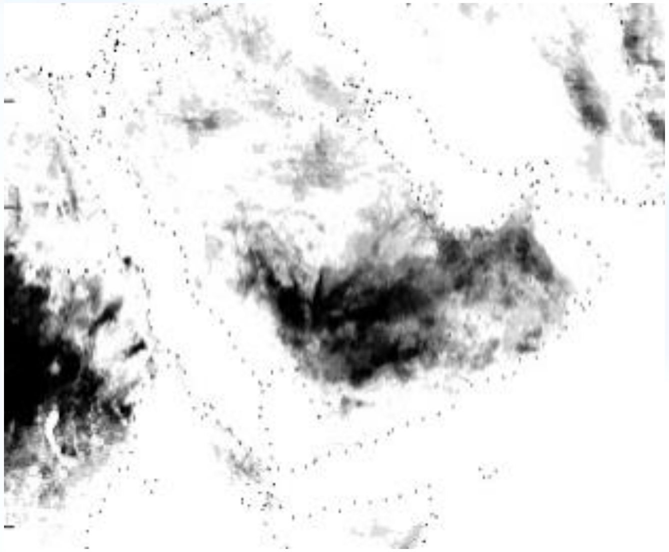
Frequency of Wind Speeds Greater Than 20 m/s

MISR Record of Location of High Near Surface Winds



Wind speeds > 20 m/s, Stereo Height ≤ 2 km AGL

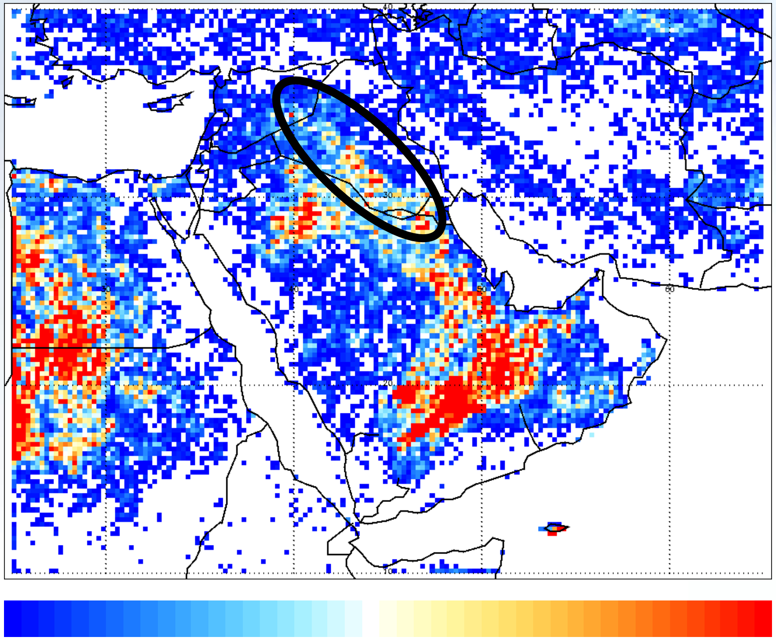
Occurrence of Dust Based on METEOSAT IR and ECMWF Winds (Feb-Apr 1999)



Léon and Legrand, Geophys. Res. Lett., 2003

Frequency of Wind Speeds Greater Than 20 m/s

MISR Record of Location of High Near Surface Winds



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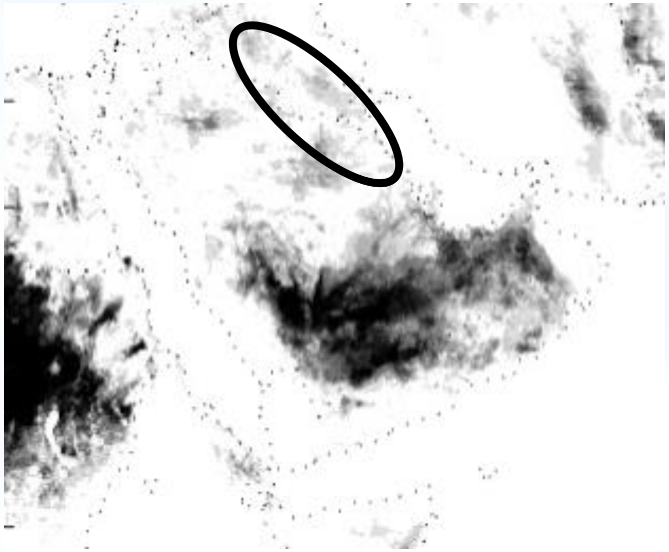
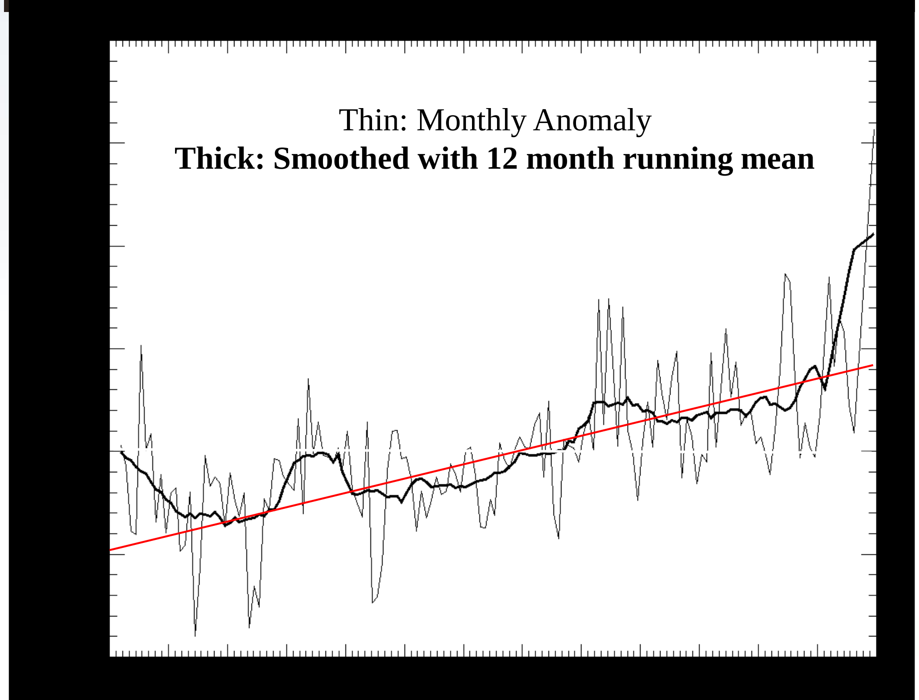


Léon and Legrand, Geophys. Res. Lett., 2003

Dust in Arabian Peninsula



'Green belts crucial to curb sandstorms'

Experts converge on Kuwait

By Cinalra Fernandes
Arab Times Staff

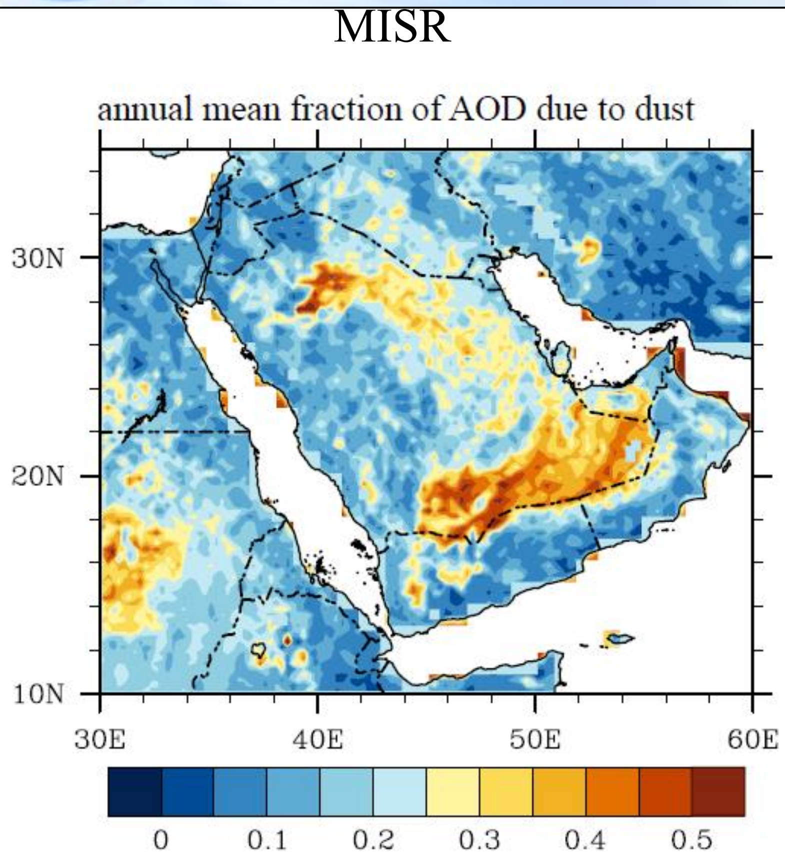
KUWAIT CITY, Nov 20: The Regional Conference on Dust and Dust storms was launched at the Sheraton Hotel on Thesday morning drawing researchers and experts from different parts of the world to present new information and exchange ideas on various issues of dust with guests from related fields.

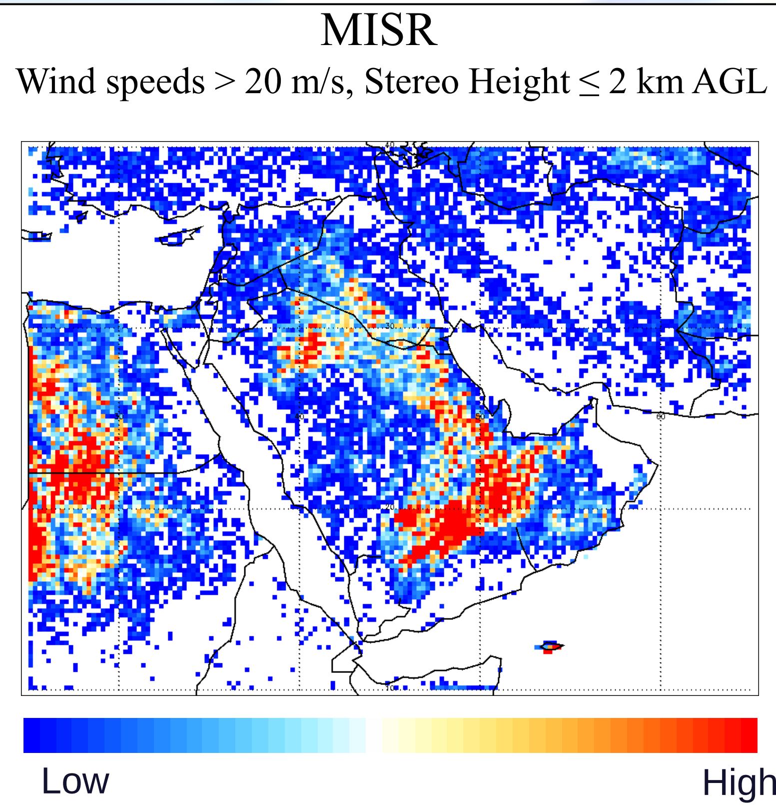
The three-day event, held under the patronage of First Deputy of Prime Minister and Interior Minister Chairman of the Higher Council, Sheikh Ahmad Al-Homoud Al-Jaher Al-Sabah will consist of 8 sessions and various rounds of discussion.

The main objectives of the conference are to identify the state of the art technology for monitoring, forecasting and early warning of dust storms, to shed more light on the composition and characteristics of dust stanns in different regions of the world and to exchange views on sustainable plans for dust storms management.

The sessions cover topics of the general characteristics of dust storms, dust composition and associated materials, the environmental impact, systems of modeling, forecasting and early warning, as well as its management and mitigation with advance approaches to dust monitoring and assessment.

SAUDI ARABIA DUST CLIMATOLOGY





Yu Y, M. Notaro, Z. Liu, O. Kalashnikova, F. Alkolibi, E. Fadda, F. Bakhrjy (2013), Assessing temporal and spatial variations in atmospheric dust over Saudi Arabia through satellite, radiometric, and station data, J. Geophys. Res. Atmos., 2169-8996, 10.1002/2013JD020677

A decadal (2018-2027) strategy for Earth Observation from Space by the National Academies of Sciences

Recommended NASA Priorities: Designated

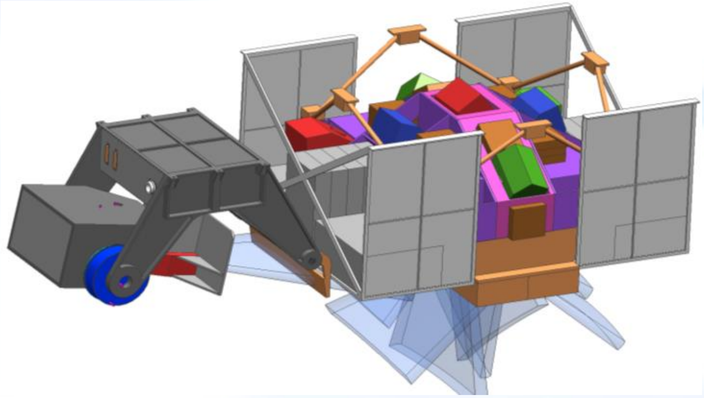
http://sites.nationalacademies.org/cs/groups/depssite/documents/webpage/deps_183919.pdf

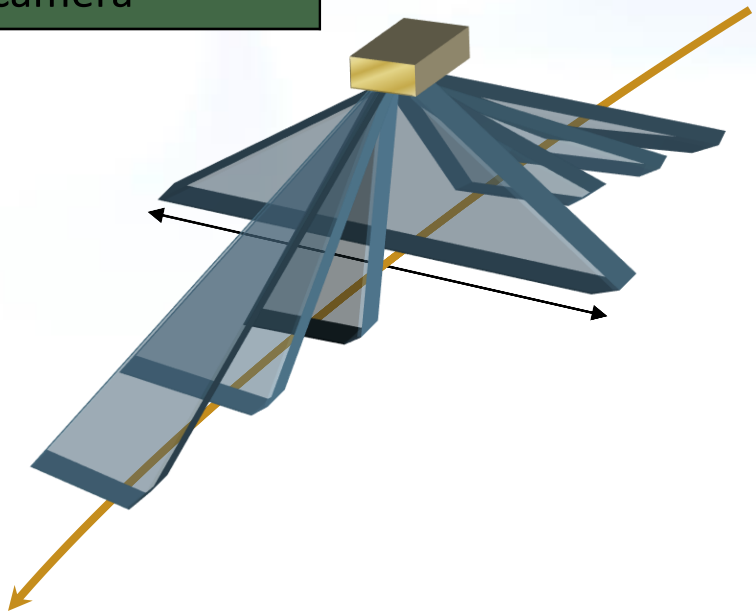
TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, & Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology & Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation & Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		

- Three tiers in the recommended NASA priorities: Designated > Explorer > Incubation

Multiangle SpectroPolarimetric Imager (MSPI)

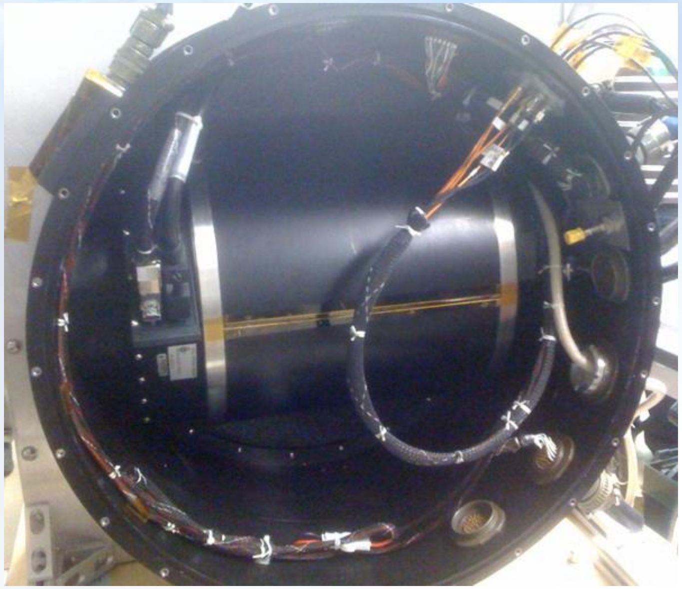
MISR	MSPI
9 cameras, 4 VNIR bands	9 cameras, UV-VNIR-SWIR bands Polarimetry in selected bands
View angles (9): Nadir, 26º, 46º, 60º, 70º	Fixed view angles (7): Nadir, 38º, 60º, 70º + gimbaled camera

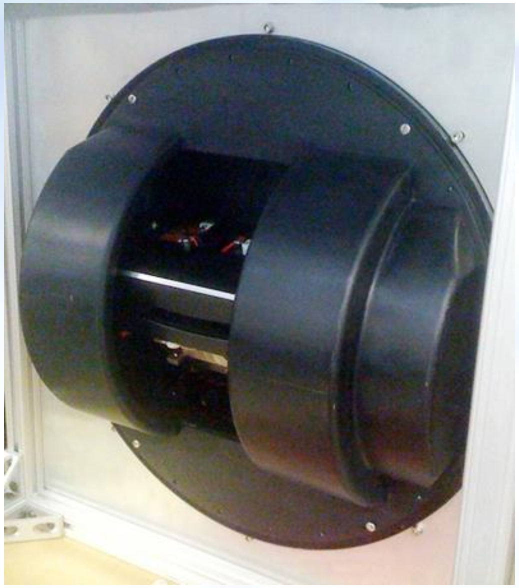




courtesy of Michael Garay at JPL

Airborne Multiangle SpectroPolarimetric Imager (AirMSPI)





Spectral bands: 355, 380, 445, 470*, 555, 660*, 865*, 935 nm (*polarimetric)

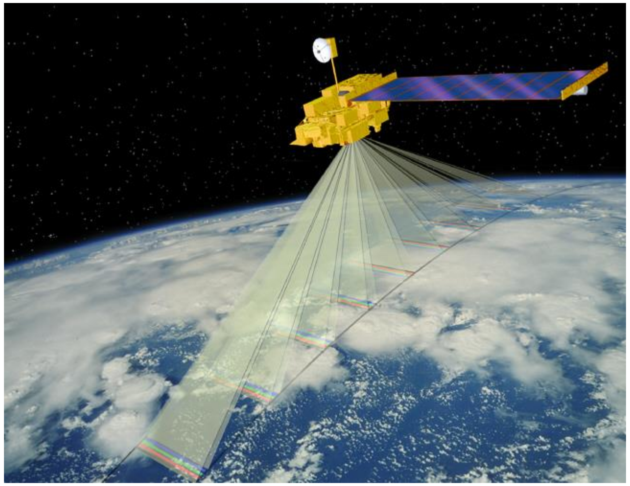
courtesy of Michael Garay at JPL

Flies in nose of NASA ER-2

Has flown: Oct 2010, Aug/Sep 2011, Jan 2012, Jul/Aug 2012, Jan/Feb 2013 (PODEX), May 2013, Aug/Sept 2013 (SEAC^{4}RS), Oct 2013

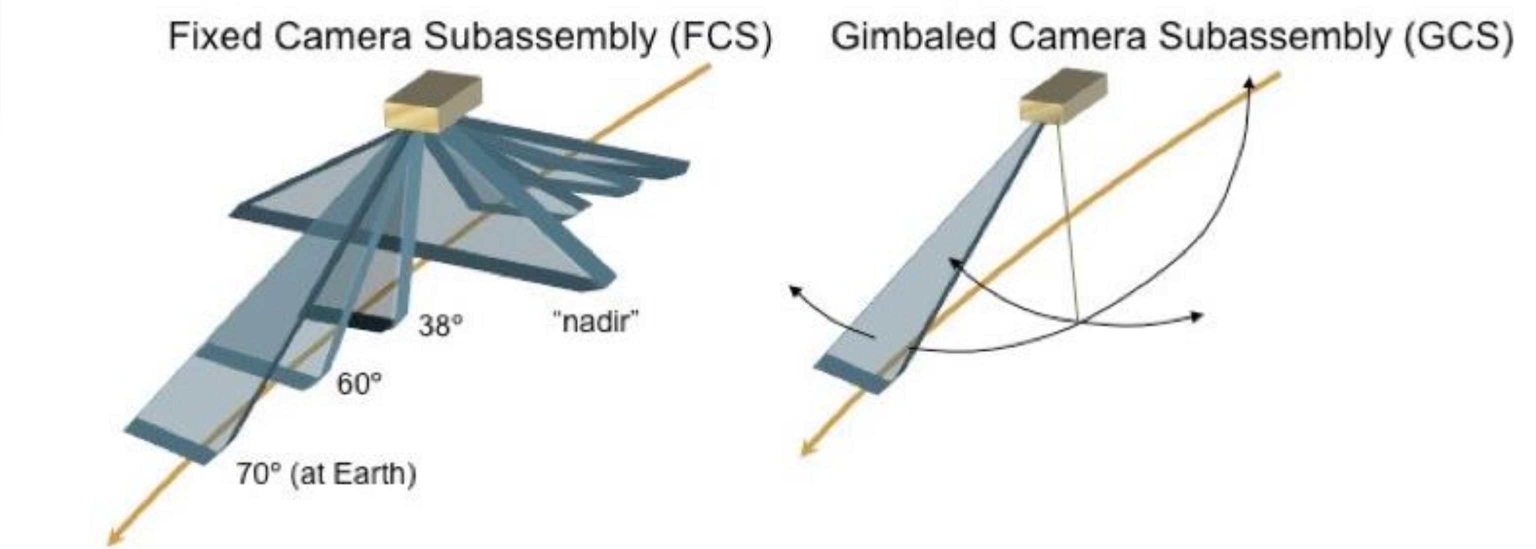
Evolution from MISR to AirMSPI

Capability	Purpose	MISR	AirMSPI
UV bands	Aerosol height, aerosol absorption	Not included	365, 380 nm
VNIR bands	Fine mode aerosols, land and ocean surface	446, 558, 672, 866 nm	445, 470*, 555, 660*, 865*, 935 nm
SWIR bands	Coarse mode aerosol, clouds, atmospheric correction	Not included	Not included
Multiangle views	Aerosols, albedo, texture	0º-70º views, 9 angles	0º-70º views with gimbaled camera
Polarimetry	Aerosol refractive index, surface texture and orientation	Not included	0.5% DOLP tolerance
Spatial resolution	Scene classification, stereo	275 m – 1.1 km	10 m – 25 m



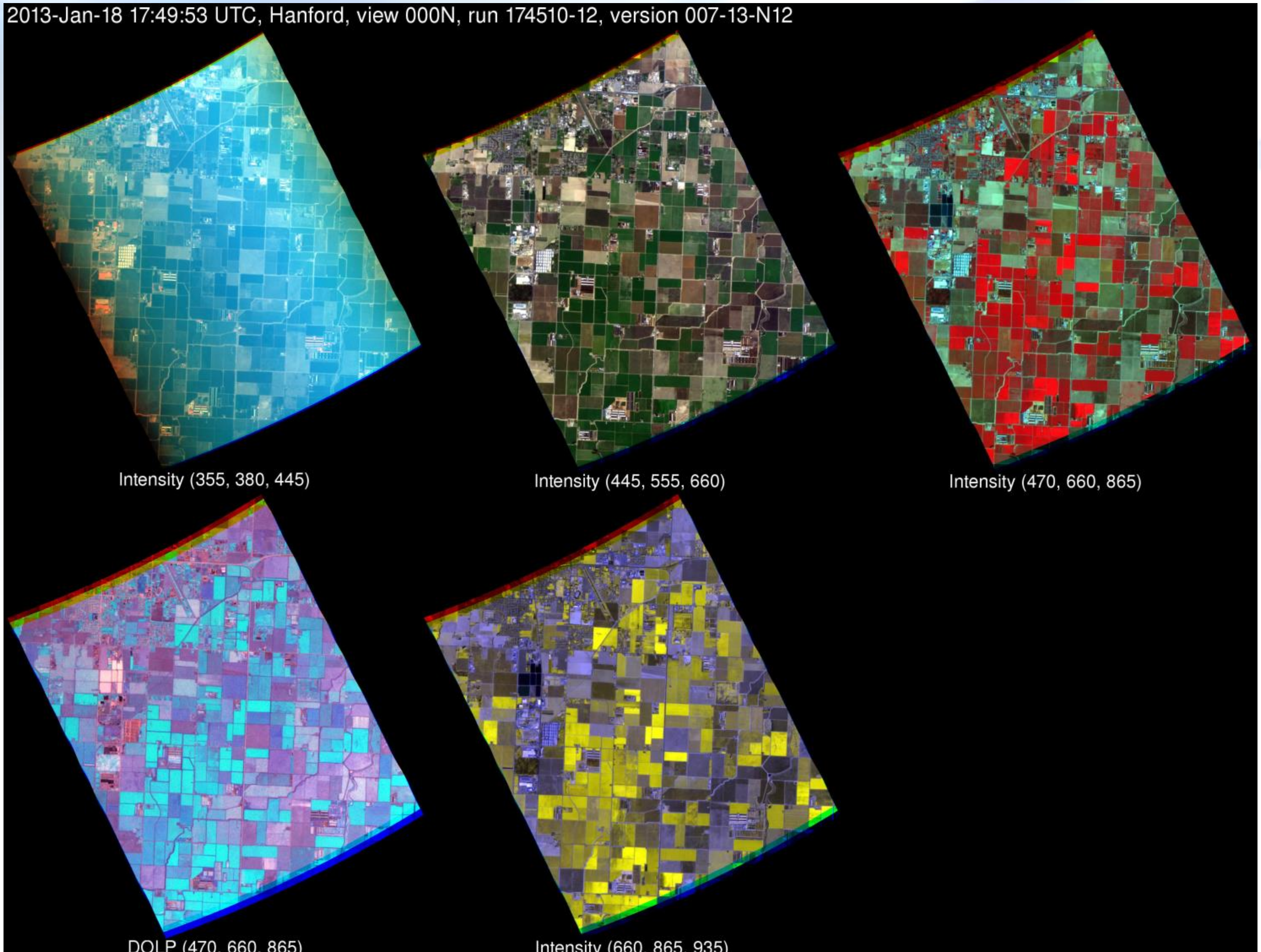
courtesy of Michael Garay at JPL

Example Sampling Strategy



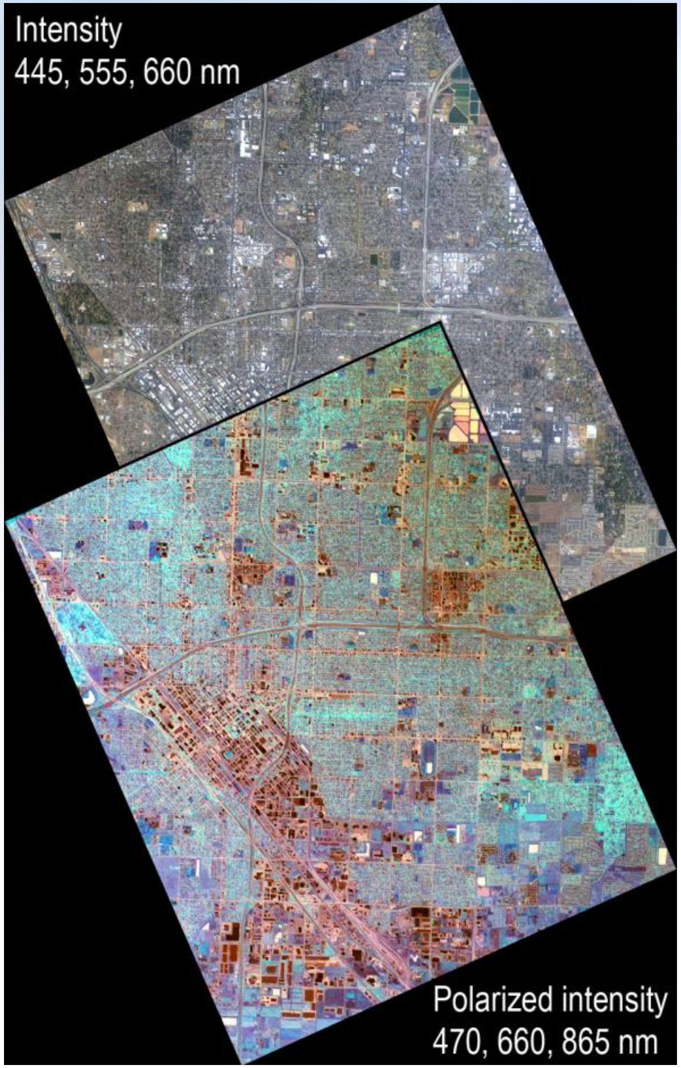
courtesy of Michael Garay at JPL

Multispectral nadir imagery over Hanford, CA on 18 Jan. 2013

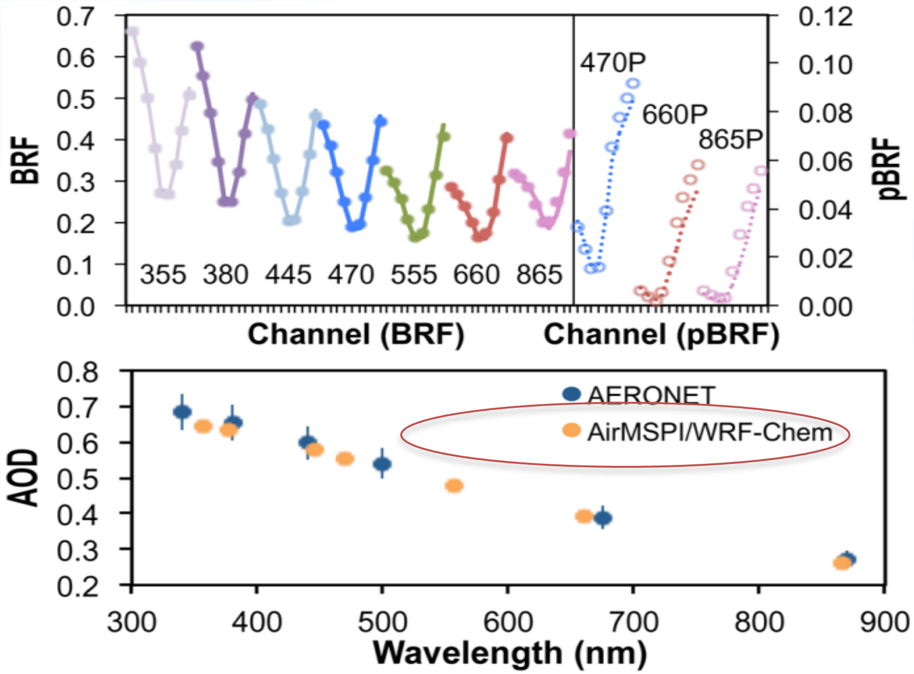


courtesy of Michael Garay at JPL

Strength of AirMSPI is its high resolution and UV + polarimetric imagery which enhance particle sensitivity



courtesy of Michael Garay at JPL

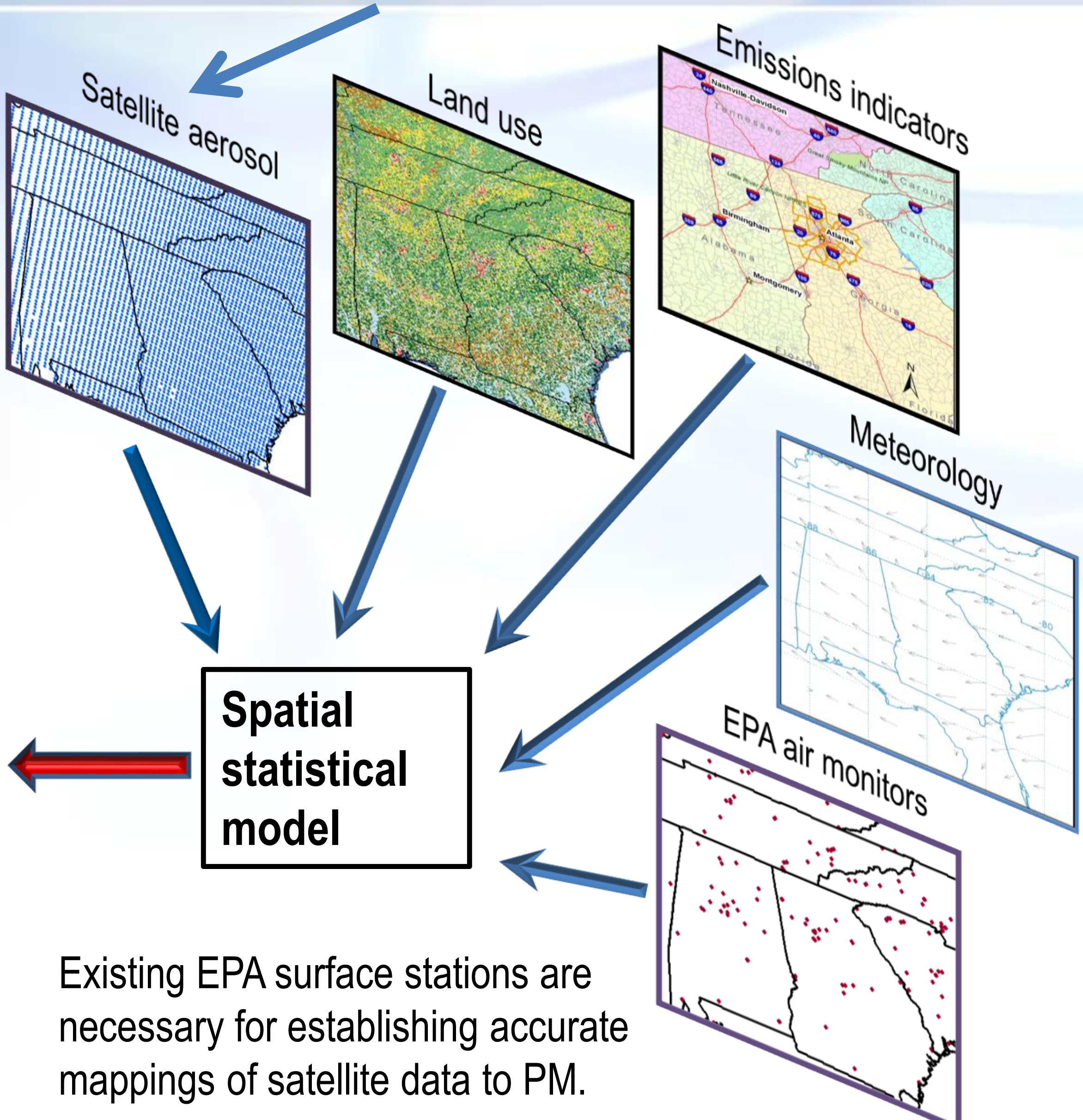


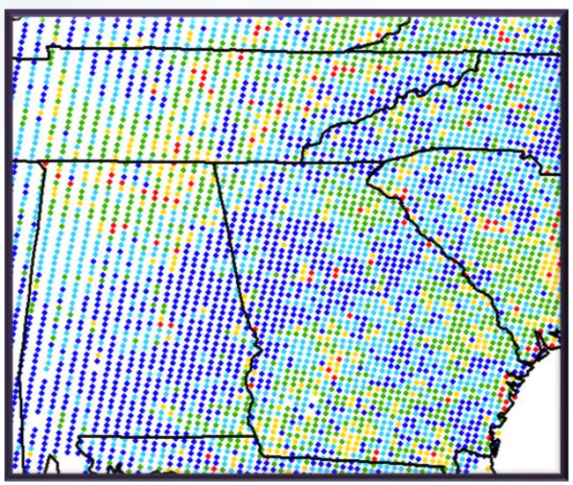
AirMSPI observations over Fresno, January 2012

An *integrated* approach, combining satellites, air quality models, and surface monitors is essential

Chemical transport model provides aerosol vertical profiles to get the boundary layer fraction of total AOD.

Satellite data, meteorology, land use, emissions indicators (e.g., population, traffic information), and EPA measurements are used as inputs to develop a statistical model to predict $PM_{2.5}$ concentration.





Predicted $PM_{2.5}$

Existing EPA surface stations are necessary for establishing accurate mappings of satellite data to PM.

courtesy of Michael Garay at JPL

- To exploit the synergies of the two JPL remote sensing instruments to provide key characteristics of aerosols.
- To investigate the relationship between speciated PM2.5 and remote-sensing data from Ground-MSPI, MTHP and air quality monitoring network in Korea

JPL's instruments

GroundMSPI
(shortwave: UV to near IR)

GroundMTHP
(microwave)

Level 1 data

- GroundMSPI: Radiance intensity, Polarization degree, Stoke's parameters
- GroundMTHP: Calibrated Cross-track Brightness Temperatures

Level 2 Products

- GroundMSPI: Aerosol optical depth, Size distribution, Refractive index, Non-sphericity
- GroundMTHP: Temperature and relative humidity profiles, Boundary Layer Thickness

Level 4 Products

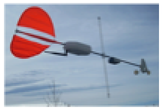
<Synergized aerosol product >

- <u>Diurnal Cycle of the Aerosol Loading</u> in the Boundary Layer
- <u>Aerosol Types C</u>lassified by Size, Shape, Single Scattering Albedo and Hydrophilic Property
- Relationship Between PM_{10} and Remote Sensing observations

Korean Instruments

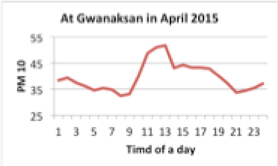
Vertical Profiles of Aerosol Loading

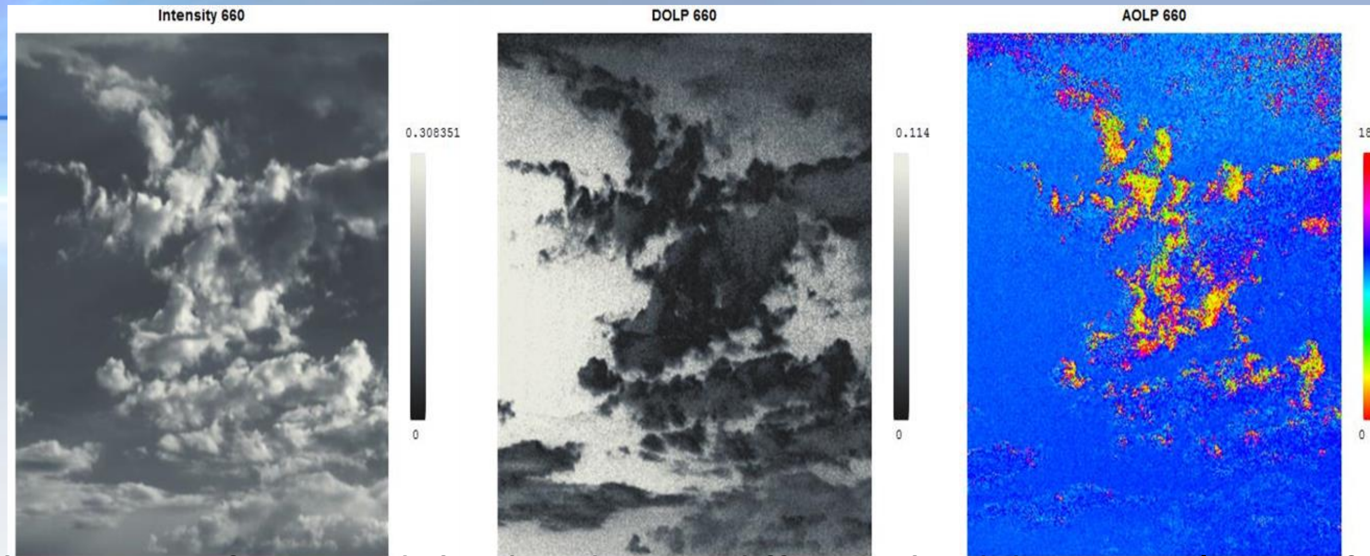
LIDAR
(from Lee et al., 2013a)



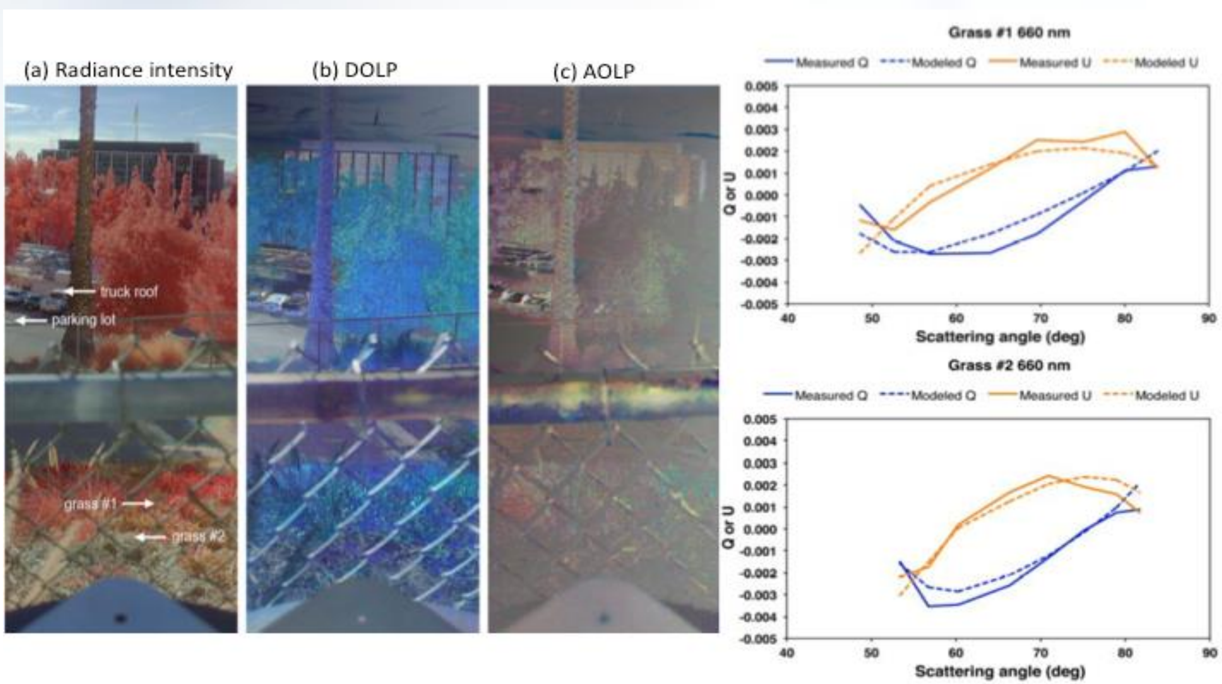
tethered sonde
(from http://www.anasphere.com/)

PM_{10} concentration (AirKorea network)



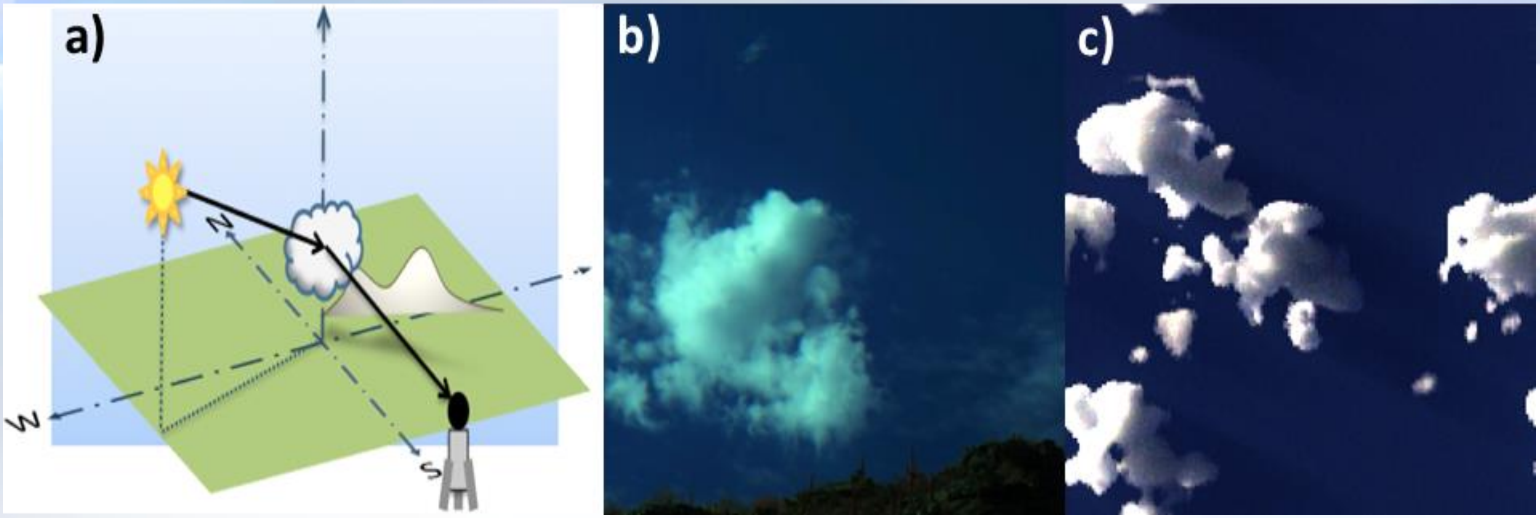


Ground-MSPI observation of scattered clouds indicating different cloud drop sizes. (From left to right) Radiance intensity, degree of linear polarization (DOLP), and angle of polarization (AOLP) at 660 nm.

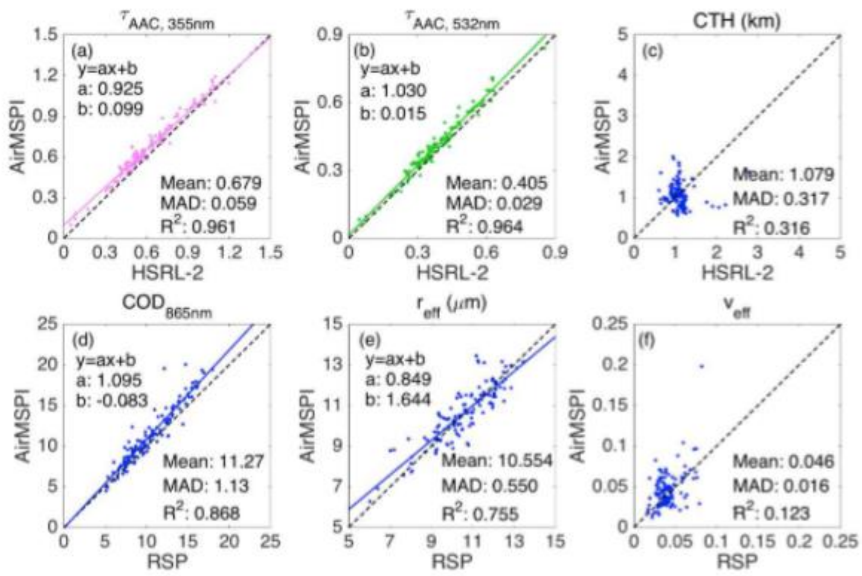


Ground-MSPI imagery taken on 6 January 2010. (a) Radiance intensity, (b) degree of linear polarization, and (c) angle of polarization at 470, 660, 865 nm displayed as blue, green and red. The plots at the right column shows the Stokes parameters Q (blue) and U (orange) as a function of scattering angles. Solid and dashed lines represent measured and simulated parameters respectively.

AOD even under cloudy conditions



(a) Viewing geometry of observation, (b) radiance measurement with Ground-MSPI, and (c) simulated radiance. (b) shows only the clouds in center of the simulated clouds in (c).



Regression of AirMSPI retrieved above-cloud AOD (AAC) against HSRL-2 lidar reference data
(from Xu et al. [2018], Coupled Retrieval of Liquid Water Cloud and Aerosol Above Cloud Properties using the Airborne Multiangle SpectroPolarimetric Imager, JGR.)

The decision to implement MAIA will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This document is being made available for information purposes only.

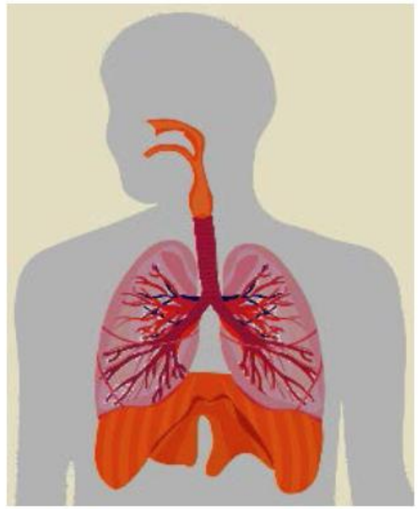
MAIA

Associating airborne particle types with adverse health outcomes

Multi-Angle Imager for Aerosols (MAIA)

The following slides are provided by MAIA PI:
David Diner
JPL

MAIA objective



Coarse particles irritate and inflame our respiratory systems.

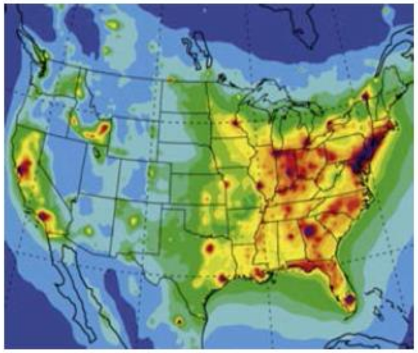
Fine particles penetrate deep into our lungs and carry toxins into our bloodstreams.

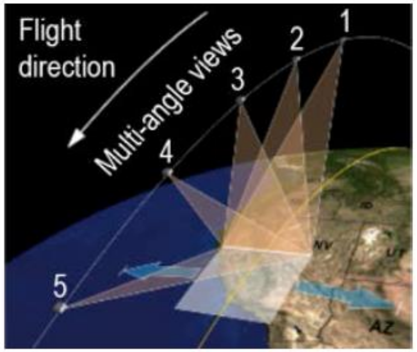
Airborne **particulate matter (PM)** is a well-known cause of cardiovascular and respiratory diseases, heart attacks, low birth weight, lung cancer, and premature death.

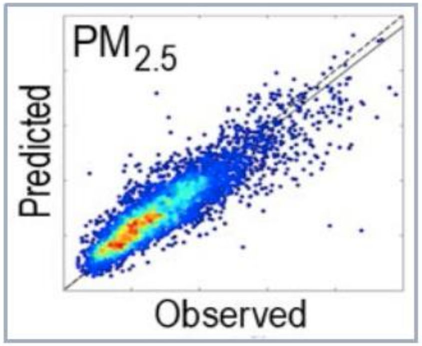
But the relative toxicity of specific **PM types** is poorly understood.

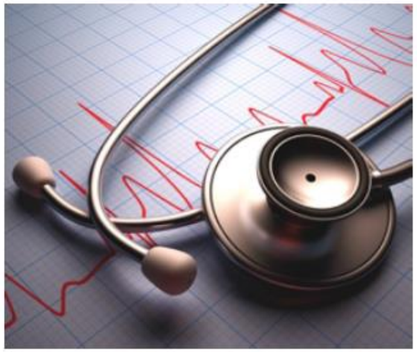
MAIA is designed to fill this gap in our understanding and enable more cost-effective pollution controls and improved health outcomes.

MAIA investigation approach









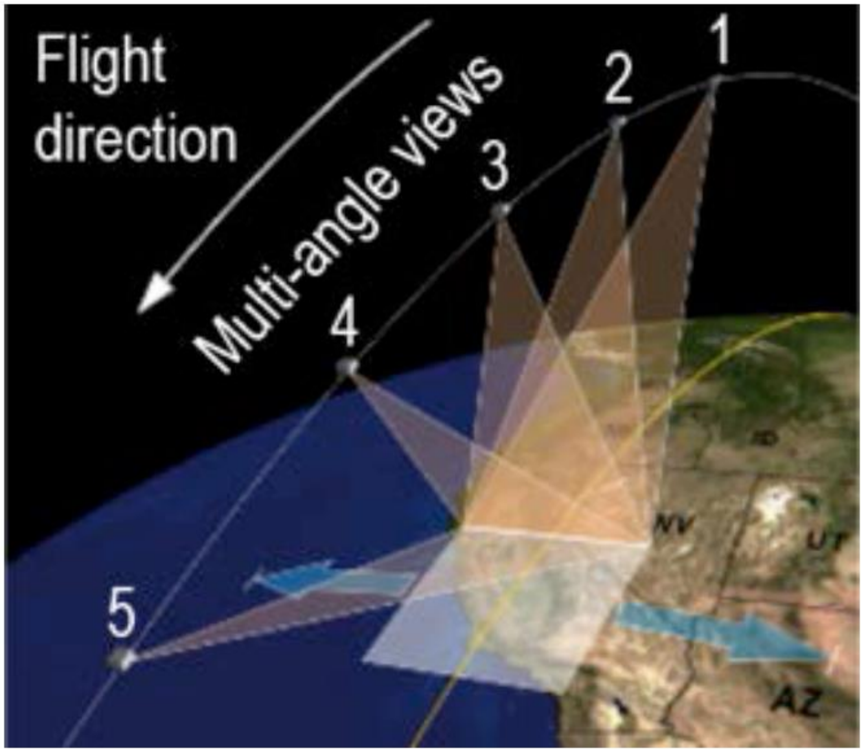
The WRF-Chem chemical transport model (CTM) provides initial estimates of the abundances of different aerosol types, along with their vertical distributions.

The MAIA instrument uses multi-angle and multispectral radiometry and polarimetry to eliminate CTM biases and retrieve fractional aerosol optical depths of different particle types.

Geostatistical models (GSMs) derived from collocated surface and MAIA measurements relate fractional aerosol optical depths to near-surface concen-trations of major PM constituents.

Geocoded birth, death, and hospital records and epidemiological methodologies are used to associate PM exposure with adverse health outcomes.

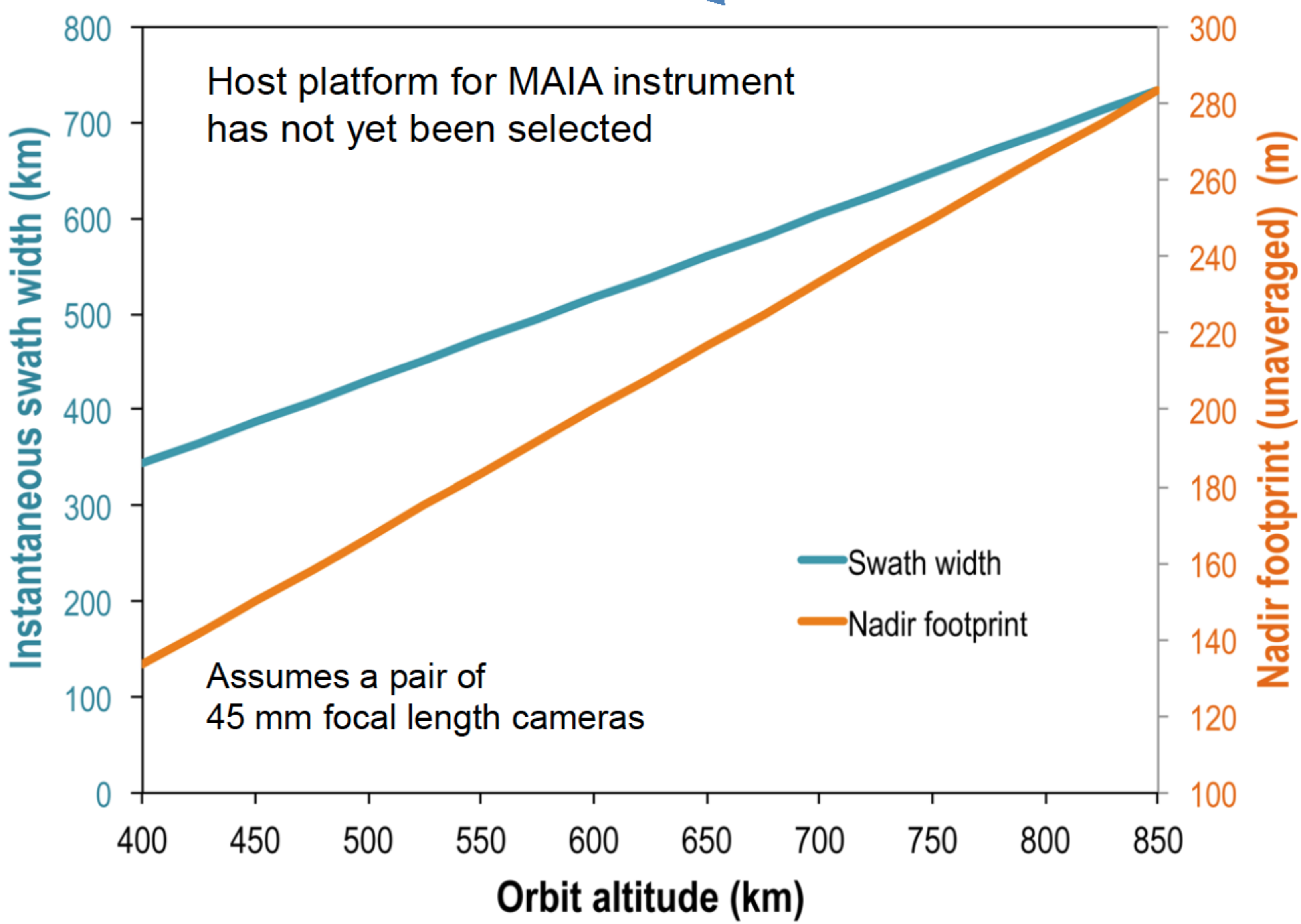
MAIA cameras are mounted on a 2-axis gimbal for targeted science operations and calibration



Along-track axis provides step-and-stare multiangle imagery (±60º at instrument)

Cross-track axis proves axis to targets off the sub-satellite track (±45º at instrument)

Swath width and spatial resolution



Summary

- Thanks to its unique multiangle viewing approach, MISR has provided AOD by components for the last 18+ years.
  - MISR AOD shows relatively good agreement with AERONET observations in East Asia and Korea
  - the high-resolution (4km) product will improve the geostatistical model to predict ground PM2.5 in Korea
- The MSPI instruments (GroundMSPI, AirMSPI, and MAIA) with advanced multichannel, multiangle, and polarimetry measurement capacities closely align with NASA's strategy for the next decade and public health program.

Proposal for collaboration (1)

- Prior to the launch of GEMS and MAIA, it is important to demonstrate the potential of air quality monitoring using them.
- Participation of Ground-MSPI in any air quality field campaigns in Korea will highlight the specific value of
  - obtaining AOD data at high temporal resolution,
  - augmenting information on aerosol types from existing observation sites near Seoul metropolitan area,
  - providing for accurate characterization of surface refraction, which is essential for the aerosol retrieval from airborne instruments and satellites.

Proposal for collaboration (2)

- Would it be possible to deploy NASA's ER-2 aircraft during the KORUS-AQ Phase II?
  - AirMSPI flies in nose of ER-2.
  - AirMSPI observations will be able to provide proof of concept before the MAIA launch or validation of MAIA observations after its launch.
  - Other ER-2 mounted instruments can add some unique values to the future campaign.
- Data availability
  - PM2.5 and speciation data availability from ground stations in Korea
  - Epidemiological data from the National Health Insurance program in Korea